Geomorphic and Sediment Assessment of the Gazos Creek Watershed, San Mateo and Santa Cruz Counties, California

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Coastal Watershed Council

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Balance Project Assignment 200022

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SUMMARY

Sedimentation and channel instability impair habitat of small populations of endangered coho salmon and threatened steelhead trout (as covered in the fishery section of the Gazos Creek Watershed Assessment and Enhancement Plan). Many landslides, gullies and bank failures contribute sediment to the creek, thereby affecting the fish habitat. The purpose of this study was to describe and quantify the sources of sediment, the transport of sediment through the watershed, and the interaction between the channel and its floodplain.

Our field work consisted of three types of data collection: 1) the inventory and measurement of sites of major sediment sources and depositional areas, 2) the measurement of bedload and suspended sediment discharge at Balance's gaging station and at other locations, and 3) the resurvey of ten cross sections first surveyed during 1998. These field tasks gave us a coherent view of the geomorphology and sediment dynamics of the Gazos Creek watershed.

The first frame of the geomorphic picture is the relationship of "bankfull" flow to "bankfull" morphology. The lower 2.5 miles of Gazos Creek has a channel morphology that just allows inundation of the floodplain during 1.5- to 2-year floods. From mile 3 upwards, the mainstem of Gazos Creek has a channel shape that does not allow inundation of the floodplain until about two to three feet above the level of the 1.5- to 2-year flood.

The second frame of the geomorphic picture is relationship of sediment sources to sediment storage. Sediment sources far outweigh sediment storage. The primary source of sediment to the creek is mainly landslides, based on the sediment sources that we surveyed. Sediment is stored behind wood jams and in floodplain terraces; however, based on our inventory and onservations, much less sediment is stored behind wood jams now, than was stored behind wood jams prior to the 1998 removal of jams.

The third frame of the geomorphic picture is the degree of sediment discharge in the watershed during water year 2002. At our gaging station, our measurements show that the sediment in motion is about 45 percent bedload and 55 perecent suspended load. The measured sediment load for water year 2002 was about 10,000 tons, or converted to a landscape lowering rate is about 0.14 millimeters per year. This value is at the low end of the range of long-term uplift rates for the local Santa Cruz Mountains region. Sediment-discharge measurements also reveal that Old Womans Creek contributes an inordinately high amount of suspended sediment compared to the rest of the watershed. Observations corroborate this finding, and add that high turbidity continues in Old Womans Creek well after a storm, when other creeks are running clear again. One impact of this persistent turbidity is to decrease the value of fish habitat in Gazos Creek downstream of Old Womans Creek.

While the assessment of the watershed focuses mainly on findings, they create a coherent enough picture of geomorphology and sediment dynamics in Gazos Creek, which allows us to suggest a recommendation that ties many of our findings and observations together. We suggest that adding wood to help create wood jams to the upper portion of the mainstem of Gazos Creek will serve multiple functions to improve fish habitat. The wood jams should trap sediment behind them, increase refuge and pool habitat for fish, and bring the channel into a closer relationship with the floodplain.

1.0 PROJECT PURPOSE AND INTRODUCTION

Gazos Creek is a focus for study because its waters are home to coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*). The goal of this study is to improve habitat for salmonids in the Gazos Creek watershed. This geomorphology (landform process) section of the Gazos Creek Watershed Assessment and Enhancement Plan (GCWAEP)addresses sources of sediment, the transport of sediment, and the interplay of sediment with the floodplain of the creek.

While reviewing historic maps of the area, we encountered conflicting names for various drainages within the watershed. For the purposes of clarification during this study we will refer to tributaries as indicated in Figure 1. The tributaries in question are the South Fork of Gazos Creek (also known as Bear Gulch) and the Middle Fork of Gazos Creek.

1.1 Hydrology

A general introduction to the Gazos Creek watershed is included in the hydrology section of the assessment report. Much of the sediment and geomorphology analysis is based on hydrologic data collected for this and a related stream gaging project on Gazos Creek. The data and report of the stream gaging is included as Appendix H-S in the hydrology section of the Gazos Creek assessment.

In this part of California, the highly episodic nature of wet years and dry years causes sediment inputs to creeks to also be highly episodic. In particular, the flood history of the watershed is important to the interpretation of observations, such as flood terraces and landslide scars. During water years 1956, 1982, and 1998 many landslides and bank failures occurred, which added large amounts of sediment to the network of creeks within the Gazos Creek watershed. Water year 1983 was also very wet, but the peak flows were smaller than during water year 1982 in most locations. Based on several sources of evidence, peak stream flow in 1982 was higher than during 1998.

In addition to the large amount of fresh sediment, high flows during the winter of 1998 left many large wood jams in the creek; many of these wood jams were removed because they were

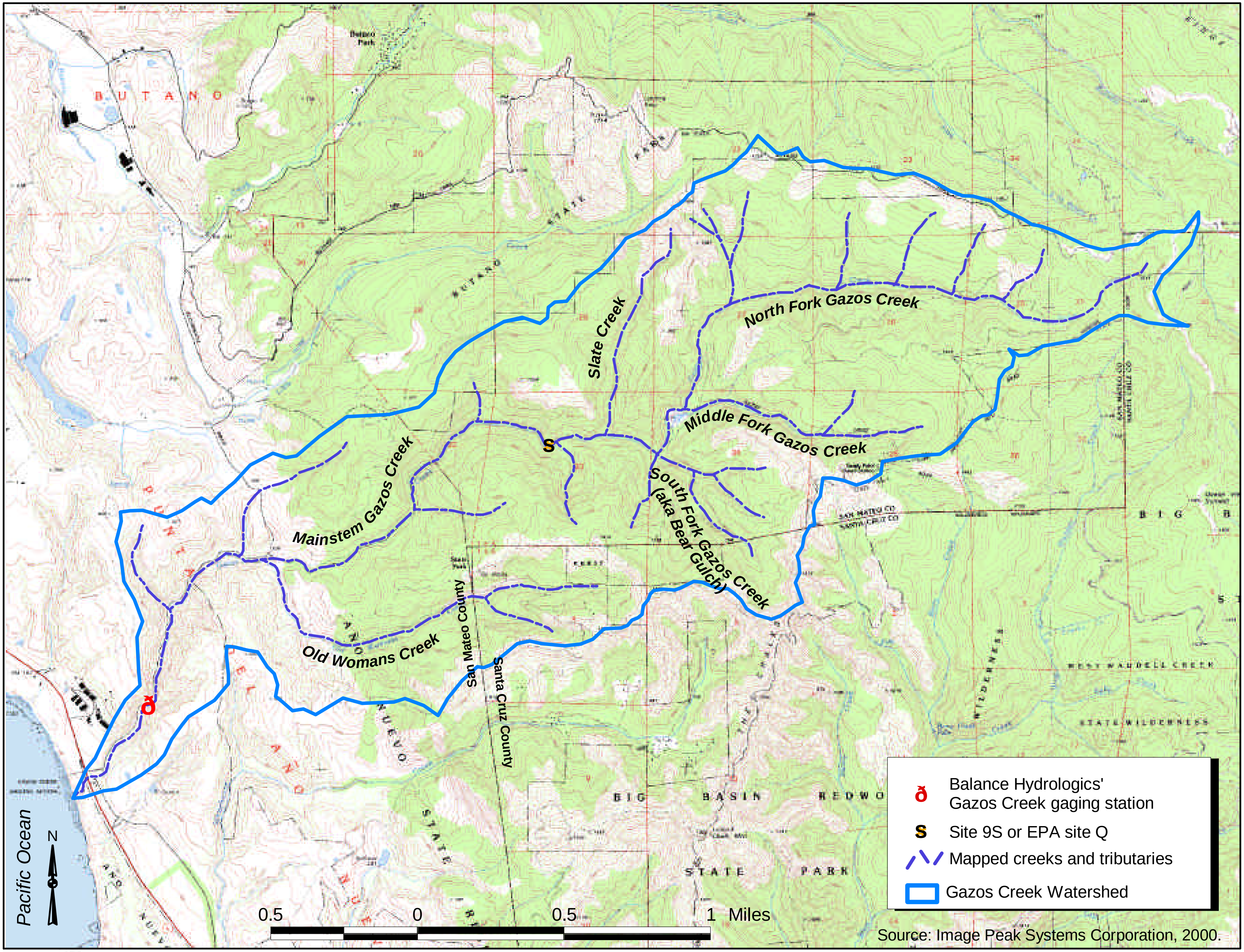

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Figure 1. Gazos Creek watershed, San Mateo and Santa Cruz Counties.
Tributary streams and primary monitoring location are noted.

Figure Location: c:\gis\santacruz\gazos.apr thought to threaten Gazos Creek Road. The removal of the wood jams has to some degree prompted this study. Large woody debris and wood jams play an important role in fish habitat, sediment storage, and geomorphology.

1.2 Geology

Geology of a watershed influences geomorphic processes such as landslides and sediment transport. The geology is shown in Figure 2. The upper portion of the North and Middle Forks of Gazos Creek are underlain by the Butano sandstone “Tb”. There is a narrow band of Santa Margarita sandstone “Tsm” adjoining the Butano. Much of the middle portion of the watershed (South Fork, Slate Creek, upper Old Womans Creek, and the mainstem of Gazos Creek) is underlain by the Santa Cruz mudstone, or “chalkrock”, “Tsc”. Many of the large landslides that we mapped occurred in the mudstone portions of the watershed (Figure 3). Many large gullies occur in the Purisima sandstone “Tp” on the north side of Gazos Creek near Cloverdale Road and farther downstream. Additional and more in-depth descriptions of the geology are included in the hydrology section of the Gazos Creek assessment. A description of many processes shaping the chalk rock geomorphology can be found in Hecht and Rusmore, 1973.

From a sediment-discharge perspective, the sandstone often occurs as large boulders, cobbles and sand-sized particles. The mudstone often enters the creek as large cobbles or smaller, sharp-edged particles. The mudstone cobbles tend to fracture easily and rapidly break down into smaller size classes of sediment. Many mudstone pieces of sediment that we collected in our bedload samples are fairly flat with rounded edges. The finer shards of the mudstone generally break down to silt-sized particles. In addition, the mudstone is also less dense than sandstone, and therefore is transported at a higher rate than similar-sized sandstone sediment.

The character of the sediment on the bed of the creek influences fish habitat. Sediment mobility of the gravel in redds affects spawning success because undersized or low-density gravel may be more easily washed away if high flows occur after the fish have spawned. Excess fine sediment, generally silt and clay-sized particles, can fill in the interstitial spaces among the gravel and reduce oxygen levels reaching fish eggs.

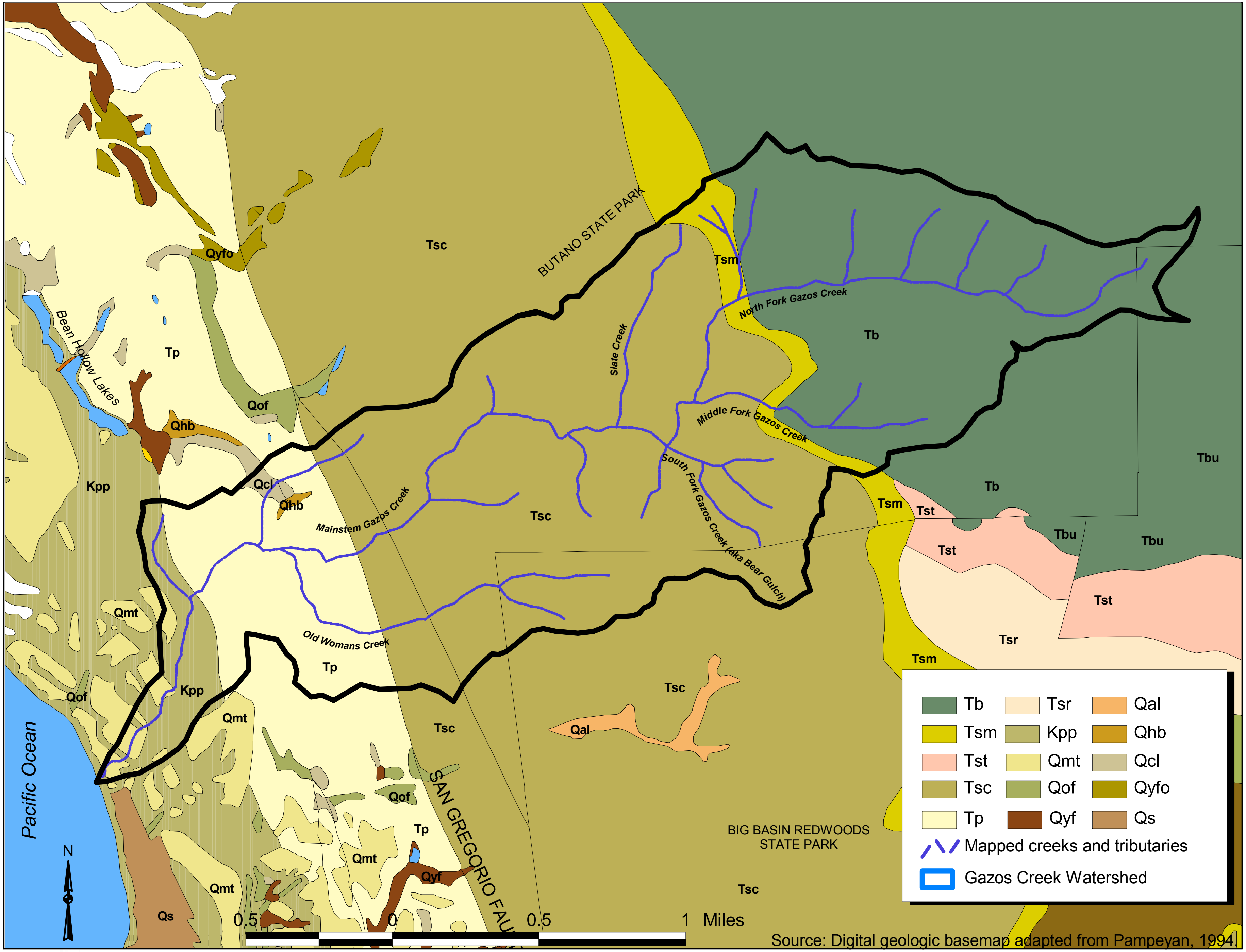

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Figure 2. Gazos Creek watershed and associated geology of San Mateo and Santa Cruz Counties.

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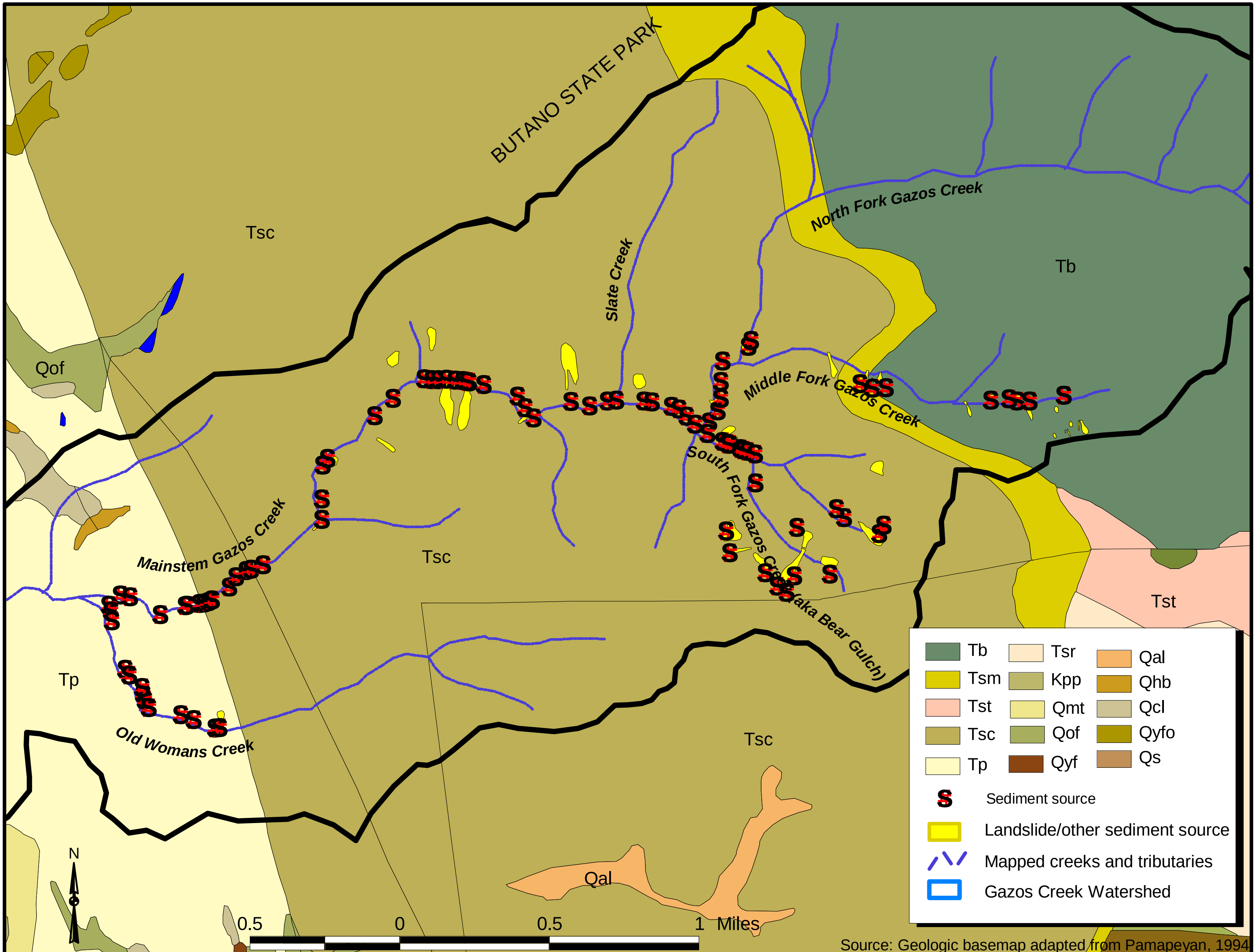

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Figure 3. Locations of inventoried sediment sources with a geology overlay: Gazos Creek watershed.

Most landslides seem to occur in the mudstone "Tsc" portion of the watershed.

1.3 Study Approach

Balance followed three main approaches to assessing the geomorphology and sediment dynamics in the Gazos Creek watershed:

1. Inventory of major sediment sources within creek channels and upland areas. The inventory included landslides, bank failures, and gullies.
2. Measurements of bedload- and suspended-sediment discharge at our gaging station to calculate a sediment budget for water year 2002.
3. The resurvey of ten cross-section profiles at a site that had been initially surveyed in the summer of 1998. That particular site was where a woody jam had been removed during May 1998. The initial survey was performed to allow evaluation of changes to the channel morphology over time.

The first two tasks are parallel methods of calculating a sediment budget for the watershed. The third task was designed to allow evaluation of changes to the channel morphology following removal of the log jam. The information from those cross sections also aided us in evaluating more general geomorphic patterns in the Gazos Creek channel.

2.0 SEDIMENT-SOURCE INVENTORY

The purpose of the sediment-source inventory was to catalog and quantify the major sources of sediment in the Gazos Creek watershed. We also used the data to construct a sediment budget for the watershed.

During water years 1956, 1982, and 1998 many landslides and bank failures occurred, which added large amounts of sediment to the network of creeks within the Gazos Creek watershed. We observed many depositional terraces that formed during 1956 and 1982, but very few that formed during 1998. We estimate that approximately half of the sediment sources that we inventoried initiated in 1982 and about half in 1998; many of those that initiated in 1982 were reactivated, and contributed additional sediment during 1998.

The field portion of the inventory of sediment sources was performed by Balance staff during October 2001. We measured dimensions of sediment sources (where sediment was missing), estimated the percent bedload of that sediment source, and estimated how long that source had been contributing sediment. We only recorded “large” sediment sources; we set the lower limit for size of sediment sources that we recorded as a volume equivalent to 1000 cubic feet (or a 10-foot cube). The minimum size criteria allowed us to concentrate our efforts on the larger sediment sources, however many of the smaller sediment sources do exist within the watershed. The sediment sources that we recorded included landslides, channel bank failures, and gullies. The locations of the sediment sources are shown in Figures 3 and 4. Details of the sediment sources are included in Appendix A.

Due to the large amount of private property in the watershed, and due to the limited time available, we were not able to visit all the sections of channel or all of the landslide sites. We inventoried the main stem of Gazos Creek from just below Cloverdale Road upstream to the North Fork of Gazos Creek; we visited a small number of upland landslide sites that we identified from air photos along the main stem. We inventoried Old Womans Creek from Gazos Creek upstream to the Santa Cruz County line. We visited many sites within the Bear Gulch watershed, with the assistance of landowners, but did not carry out a systematic inventory. We inventoried much of the Middle Fork Gazos Creek, but were limited to public property along the County road right of way. We inventoried the short downstream portion (about ¼ mile) of the North Fork Gazos Creek that we had land owner permission to visit.

One particular set of sediment sources that we did not have time to inventory are the gullies on State Parks and POST land on the north side of Gazos Creek near Cloverdale road. Steve Singer has subsequently provided us with some information about these gullies, some of which are already being treated. More information can be found about the size and location of gullies in Mr. Singer’s report (Singer, 2000).

At the same time that Balance staff inventoried sediment sources, we also inventoried significant wood jams, and the amount of sediment stored behind the wood jams. The information on wood jams will be covered in section 3 of this report.

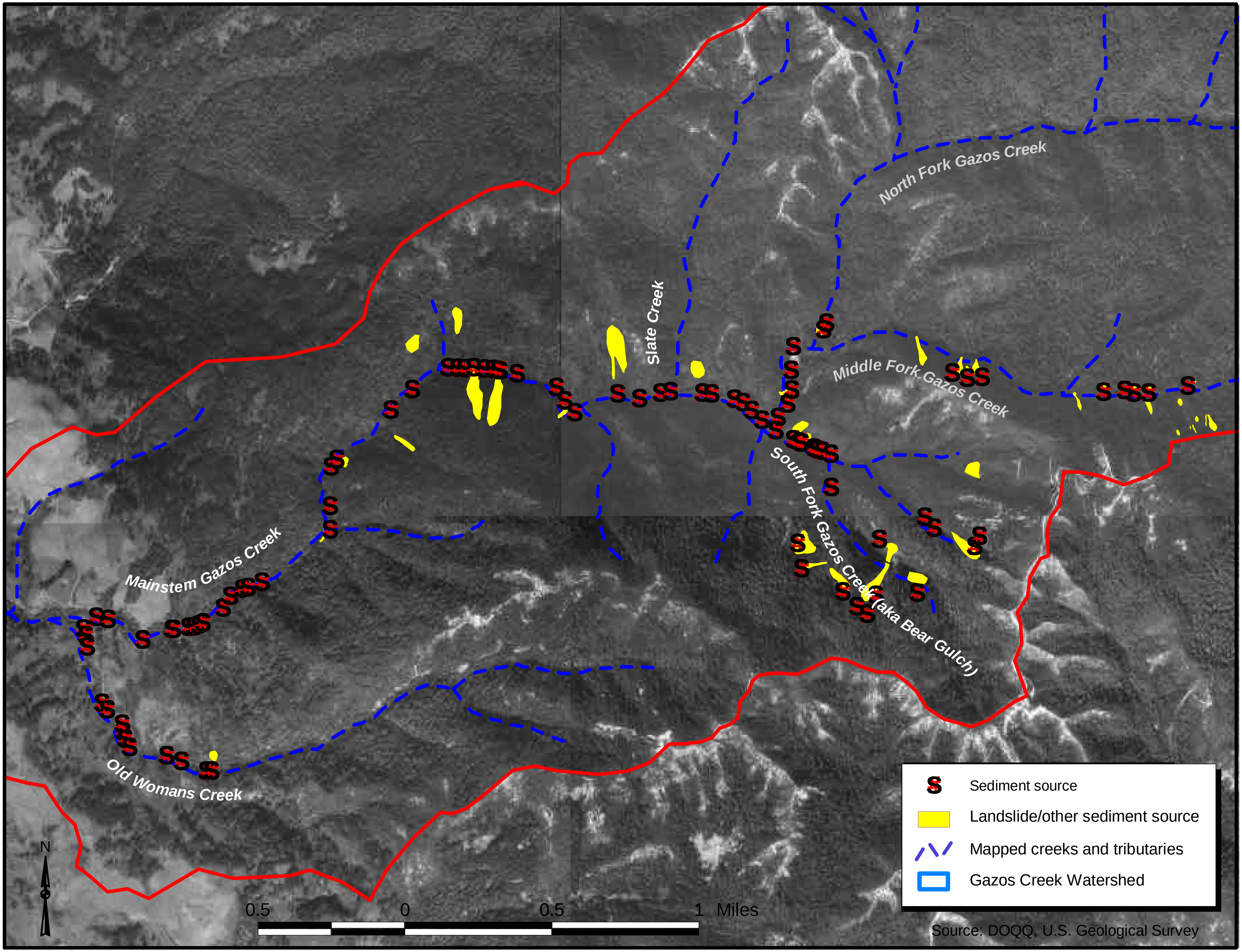

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Figure 4. Locations of inventoried sediment sources: Gazos Creek watershed.
Large sediment sources are shown as polygons, smaller sources are shown as dots that are generally larger than the actual source.

2.1 Measuring sediment sources

Generally, measurements of the dimensions of sediment sources were made with reel tapes and surveying rod. Occasionally, for dimensions that would have taken too long to measure directly, we estimated distances; this was done after measuring similar distances at previous sites.

We needed to balance the precision of measuring each sediment source with the need to record many sediment sources throughout the watershed; had we been able to allot more time, we could have documented a larger number of sites. We performed the measurements with a level of accuracy and precision that we felt was appropriate to the uses for data that we were collecting. Many of our measurements are probably only accurate to approximately 10 percent of their value.

2.2 Sediment inventory totals

The sediment source data is presented in Appendix A. We totaled the volumes of the sediment sources that we inventoried into Table 1, and also made estimates to include portions of the Gazos Creek watershed that we were not able to visit. The values are approximate, but we calculate sediment source totals of about 390,000 (+/- 150,000) tons of sediment; sediment stored behind woody jams has already been subtracted to calculate the "net sediment source volumes". We estimate that the amount of sediment that we calculated in Table 1 should be roughly representative of sediment released to Gazos Creek since (and including) 1982. This value is comparable to sediment totals calculated by our sediment-discharge method (in section 4).

During the field inventory, we estimated the year in which we thought that each sediment source had been initiated (Appendix A). Even though we could have calculated an average amount of sediment per year, we do not think that averaging sediment yield on a per-year basis is valid, due to the episodic and irregular nature of sediment delivery and transport. The large majority of sediment is moved during the years which have numerous large storms such as water years 1956, 1982, and 1998. This pattern can be seen in Tables 2 and 3, where sediment discharge for water year 1998 is much higher than the subsequent years.

Table 1. Sediment inventory volume and mass calculations: Gazos Creek watershed

	Net Sediment Source Volume	Sediment Density	Net Sediment Source Mass	Sub-watershed Area	Average date of source inititation
	(cub. feet)	*(tons/cu.m)*	*(metric tons)*	*(sq. miles)*	
Old Womans Creek	213,624	1.75	10,587	1	1988
Gazos Creek (up to Middle Fork)	1,419,991	1.5	61,931	3	1987
Bear Gulch	1,519,850	1.5	66,286	0.7	1984
Middle Fork Gazos Creek	352,800	1.75	17,485	0.7	1956
51% of the inventoried source sediment is bedload size material			156,290	5.4	1983 subtotal of *inventoried* sediment sources
Uninventoried sections of the watershed:					
Old Womans Creek (private portions)			36,849	0.7	(based on Bear Gulch and Old Womans)
Gazos Creek (below Cloverdale Road)			15,881	1.5	(based on Old Womans Cr.)
Bear Gulch (private, un-inventoried portions)			21,780	0.23	(based on Bear Gulch)
Middle Fork Gazos Creek (private portions)			11,740	0.47	(based on Middle Fork)
North Fork Gazos Creek (private)			53,205	2.13	(based on Middle Fork)
other tribs like Slate Creek (private)			85,225	0.9	(based on Bear Gulch)
change in bed storage, Gazos Cr. main stem			7,850	0.013	(based on repeated cross-section surveys)
		Total	**388,820**	11.3	
		+/-	**150,000**		

Notes:

"Net" sediment source volume = sediment sources - sediment storage, and includes bedload and suspended load sediment.

Sediment mass from "uninventoried sections of the watershed" sections was scaled by sub-watershed area and then scaled by rates from a sub-watershed of similar geology and steepness.

Our estimate of uncertainty of the calculated total is subjective and takes many sources of uncertainty into account.

We asssume that these estimates are lower than the actual sediment sources, because we did not record every sediment source that we saw (small sources were excluded), and we did not account for many upland areas because we mainly focused on the creek channels.

Dissolved sediment mass is not explicity accounted for in this table, but is assumed to be small during wet years, when most sediment is transported.

Sediment density (Hecht and Golling, 1982) for this purpose is the bulk density of the sediment sources, which are sometimes soil and sometimes bedrock, and assumes 30% porosity.

"Average date of source initiation" is weighted by the volume of the sediment source and is based on those sources to which we assigned a date; the average date reflects the balance between recently activated sediment sources (usually 1998) and older sediment sources (often 1982 and 1956).

Percent bedload was estimated individually for each sediment source in the field; the average is again weighted by the size of the source.

Table 2. Calculation of lowering rates from sediment yield, for three Santa Cruz Mountain creeks

Water Year	Bedload Sediment	Suspended Sediment	Total Flow	Flow-Averaged TDS	Dissolved Sediment	Total Sediment	Sediment Particle Density	Watershed Area	**Landscape lowering rate**
	(tons)	*(tons)*	*(ac-ft)*	*(mg/l)*	*(m.tons)*	*(m.tons)*	*(m.tons/m^3)*	*(sq.mi.)*	***(mm/yr)***
Gazos Creek near Highway 1									
2002	4,784	5,481	8,655	176	1,879	**11,211**	2.3	11.3	**0.14**
Corte Madera Creek at Westridge Drive									
1998	43,251	148,912	11,346	350	4,899	179,592	2.65	6.0	**3.8**
1999	7,106	8,113	3,869	350	1,671	15,506	2.65	6.0	**0.33**
2000	17,007	40,174	4,733	350	2,044	54,026	2.65	6.0	**1.13**
2001	391	1,011	1,561	350	674	1,949	2.65	6.0	**0.041**
2002	1,482	3,661	1,694	350	731	5,407	2.65	6.0	**0.11**
Los Trancos Creek at Arastradero Road									
1998	5,418	3,398	6,444	400	3,180	11,195	2.65	5.27	**0.27**
1999	1,135	2,639	2,507	400	1,237	4,668	2.65	5.27	**0.11**
2000	1,202	754	2,084	400	1,028	2,807	2.65	5.27	**0.067**
2001	200	119	881	400	435	724	2.65	5.27	**0.017**
2002	158	410	1,066	400	526	1,042	2.65	5.27	**0.025**

Notes:

"m.tons" = metric tons

Flow-averaged TDS is an estimate, based on measurements of specific conductance and converted by a factor of 0.7 (mg/l)/(us).

"Dissolved sediment" is a rough estimate based on TDS which also includes a small amount of dissolved constituents in rain water.

Bedload discharge and suspended-sediment discharge were measured; dissolved sediment was estimated.

Peak flow was not used in the calculations, but is included for reference as one measure of how wet the year was.

Sediment particle density (Hecht and Golling, 1982) for this purpose represents the bedrock density because we are comparing total sediment yield to uplift rates. The Santa Cruz mudstone "chalkrock" bedrock in the Gazos Creek watershed is less dense than bedrock in many other areas.

Table 3. Calculation of sediment yield from landscape lowering rates: Gazos Creek watershed, water years 1998 to 2002

Water Year	Landscape lowering rate Corte Madera Creek	Landscape lowering rate Los Trancos Creek	Lowering rate for Gazos Creek based on Corte Madera Creek	Lowering rate for Gazos Creek based on Los Trancos Creek		Sediment Yield for Gazos Creek based on average of Los Trancos and Corte Madera Creeks	
	(mm/yr)	*(mm/yr)*	*(mm/yr)*	*(mm/yr)*		*(m.tons)*	
1998	3.8	0.27	*4.8*	*1.5*		*246,417*	
1999	0.33	0.11	*0.41*	*0.64*		*41,187*	
2000	1.13	0.067	*1.4*	*0.39*		*71,111*	
2001	0.041	0.017	*0.052*	*0.10*		*5,916*	
2002	0.11	0.025	**0.14**	**0.14**		**11,211**	
			6.8	2.8		**375,842**	**Total (5-year period)**
			(mm)	*(mm)*	**+/-**	**150,000**	
						(metric tons)	

Notes:

Landscape lowering rates for Gazos Creek scaled from water year 2002 value by rates in Corte Madera Creek; we note however, that equating lowering rates from Corte Madera Creek to Gazos Creek is a very rough approximation.

Sediment yields for previous years of Gazos Creek scaled from water year 2002 value by lowering rates.

Sediment yields for Gazos Creek include dissolved load; dissolved load should be a minimal factor during wet years, although it can be a significant factor during normal or dry years.

Our estimate of uncertainty of the calculated total is subjective and takes many sources of uncertainty into account.

Values with more than two significant figures are the the result of electronic calculations and do not imply increased precision.

Table 1 averages the year of initiation for the various sub-watersheds; this averaging was done weighted by the size of the source (so larger sediment sources have a bigger influence on the average). The averages for most parts of the watershed (the mid to late 1980's) indicate that about half of the sediment sources initiated in 1982 and half initiated in 1998. Because many of the sources which initially contributed in 1982 were reactivated in 1998, the sediment totals that we inventoried are probably representative of sediment generation since (and including 1982). Even though we calculated dates for the volume of sediment, converting the totals to a "per-year" basis would not be valid because of the episodic nature of sediment contributions and the wide variability between years.

The average date of initiation sources from the Middle Fork Gazos Creek (about 1956) is much older than the rest of the watershed (Table J1); this matches our observations that few recent sources of sediment are evident along the Middle Fork (at least for the portions that we were able to visit). Many of the landslide scars had been revegetated by mature trees.

2.3 Caveats of calculations in Table 1

In order to construct a watershed-wide sediment budget, we needed to account for sections of the watershed that we did not inventory. We did this by comparing watershed areas that we had inventoried to areas that we had <u>not</u> inventoried directly. Sediment mass from "uninventoried" sections was scaled by sub-watershed area and associated with rates from a sub-watershed of similar geology and steepness; this calculation is performed in Table 1. Sediment density (Hecht and Golling, 1982) for this purpose is the bulk density of the sediment sources, which are sometimes soil and sometimes bedrock, and assumes average 30 percent porosity. Santa Cruz mudstone is less dense than sandstones, which outcrop in other parts of the watershed. We assume that these source-inventory estimates are lower than the actual sediment sources, because we did not record every sediment source that we saw (small sources were excluded), most road-surface erosion was not inventoried, and we did not account for many upland areas because we mainly focused on the creek channels, therefore the stated uncertainty of 150,000 tons is mainly in the upward direction. This estimate of uncertainty of the calculated total is subjective and takes many sources of uncertainty into account.

2.4 Dating sediment sources and deposits

We employed several methods of estimating when sediment sources originated, and how long since they may have stopped contributing sediment. Some sources were still actively contributing sediment to the creek in October 2001; other sources had been largely revegetated with young pioneer species of vegetation. We often estimated the most recent contributions from a sediment source by estimating the age of vegetation growing on the surface of the source. Some landslide sediment sources had multiple scarps, and separate or combined sections of differing ages.

For large sources of sediment, that were visible from aerial photos, we were able to bracket the time period that they had occurred by comparison of sequential air photos. For recent landslides that we compared air photos from 1993, 1995, and 2000 to verify our field dating procedures. We also consulted aerial photos from 1953. We often assumed that sediment sources occurred as a result of large storms such as in water years 1956, 1982, 1995, and 1998.

In our work, we also found it useful to date sediment deposits, such as flood terraces. The flood terraces were often vegetated with even-aged stands of alders, indicative of trees that colonized in the same year after fresh sediment had been deposited along the bank of the creek. In some locations we found broken trees and counted their rings to estimate their age; at other locations we estimated the age of the alders (and therefore the terrace deposit). We found that trees of the same age generally had a smaller diameter if they were located on the south side of the creek (less sunlight), than trees on the north side of the creek (more sunlight). The major terraces that we identified were from water years 1956, 1982, and 1998. We also counted rings of cut or broken redwood trees at several locations, which aided us in estimating the age of trees based on their diameter.

2.5 Roads as Sediment Sources

Besides the roads currently used, numerous abandoned roads cross the hillslopes, where forestry and other activities took place in the past. The CWC has performed a partial mapping of the many roads and former roads in the Old Womans Creek portion of the watershed.

Balance was not tasked with calculating sediment contributions from roads. In a few cases, particularly on the dirt section of Gazos Creek road along the Middle Fork, we did note a few sections where deep erosion appeared to have taken place. Those sections are noted in Appendix A and are included in the sediment budget.

Roads contribute sediment to the creek in several ways. One way is surface erosion from dirt-surfaced roads. Another way is erosion by the concentrated runoff that originates on the road, and then erodes the bank downslope from the road, often at the outfall of a culvert. A third way happens where dirt or paved roads are cut across a slope, and destabilize the uphill slope; the soil and rock can fail by landsliding onto the road or into a road-side ditch, and then be carried into the creeks by surface flow on the road or in the ditch. The fill sections of old cut-and-fill type roads can also fail, contributing sediment downslope.

2.6 Bioturbation

During our sediment inventory, we observed several stretches of riparian zone that appeared to have been churned by feral pigs, particularly along the Middle Fork of Gazos Creek. This churning provides readily available sediment and organic matter that may enter the creek system. We believe this to be a minor issue in terms of the sediment budget, but we are including it for completeness.

3.0 WOOD JAMS AND SEDIMENT STORAGE

During the watershed inventory that we performed to identify major sediment sources (October 2001), we also inventoried “significant” wood jams. We defined wood jams as “significant” that included two or more logs spanning the creek. The amount of sediment being trapped behind the wood jams was also measured and recorded. Balance’s inventory of wood jams differs from the cataloging of large woody debris (LWD) that is detailed in the fishery sections of the Gazos Creek Assessment. LWD also provides fish habitat and may trap sediment, but we make a distinction between a wood jam that spans the creek and individual pieces of LWD.

The wood jam locations that we inventoried are shown in Figure 5. We measured several aspects of the wood jams, such as depth of the pool downstream from the wood jam, height of

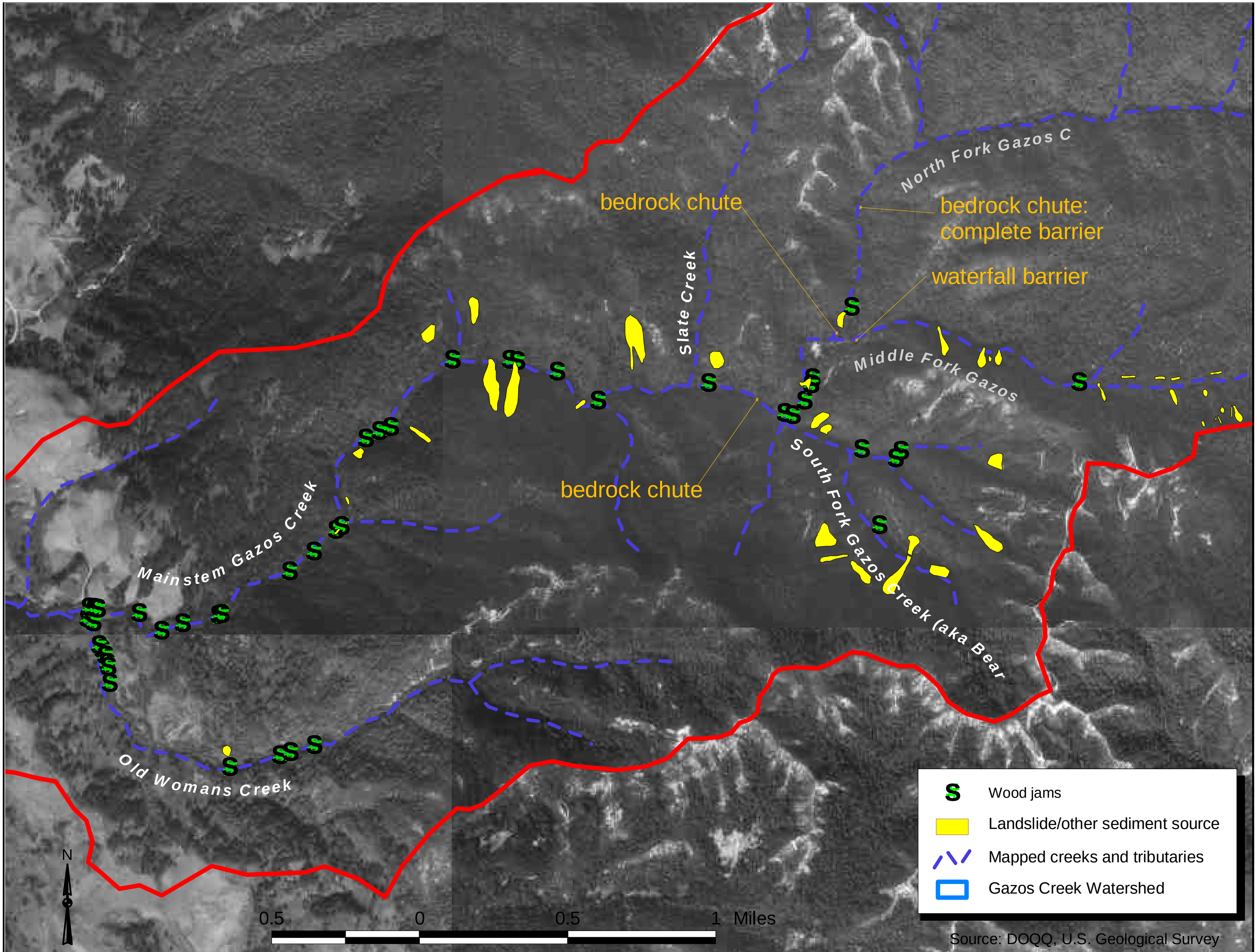

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Figure 5. Locations of inventoried wood jams: Gazos Creek watershed.

The locations are shown as dots, the magnitude of the wood jams in Figure 6 and detailed in Appendix B.

the wood jam, length of the jam, width of the jam, the number of logs in the jam, and other parameters. Details of the wood jams and sediment stored by the wood jams are listed in Appendix B. A longitudinal plot of the wood volume and sediment stored behind wood jams (Figure 6) shows that few large wood jams are present upstream from about mile 3.0, and that the wood jams are currently storing a small amount of sediment compared to the size of sediment sources in the watershed.

During the inventory, we noticed many locations where large wood jams had been removed. These removed wood jams were much larger than almost all of the active wood jams that we inventoried. One exception is the wood jam that is located at mile 3.0 in Figure 6. That wood jam seems to have formed in 1982, based on the large sediment terrace behind it that is characterized by even-aged alders that seem to have colonized that terrace in 1982. The mile-3.0 wood jam either decayed and was breached naturally, or was removed, and is about the same size as many of the removed wood jams that we noticed. The mile-3.0 wood jam stores a significant amount of sediment (about 32,000 cubic feet) when compared to the sediment sources in Table 1 and Appendix A, even though a large part of the sediment is no longer there.

4.0 GAGED SEDIMENT-DISCHARGE BUDGET

Balance's primary stream gage is located in Gazos Creek, about one-half mile upstream from Highway 1, and about one-quarter mile upstream of the pump-station diversion (Figure 1), and is sometimes referred to as station GCDFG. We gaged stream flow at this site with automated equipment, the end product of which was a hydrologic summary and sediment yield for water year 2002 (Owens, Shaw and Hecht, 2003, also referred to as Appendix H-S in the hydrology section of the GCWAEP).

During site visits we collected bedload and suspended-sediment samples from Gazos Creek at the gaging station. The sampling details are listed in Table 4. We converted the measured sediment samples to sediment load in units of tons per day. As is typical, the sediment samples form a distinct relationship that depends on stream flow. We then used the sediment measurements in conjunction with the record of streamflow to calculate sediment discharge at 15-minute intervals for the year, from which a yearly total was calculated; the total for water

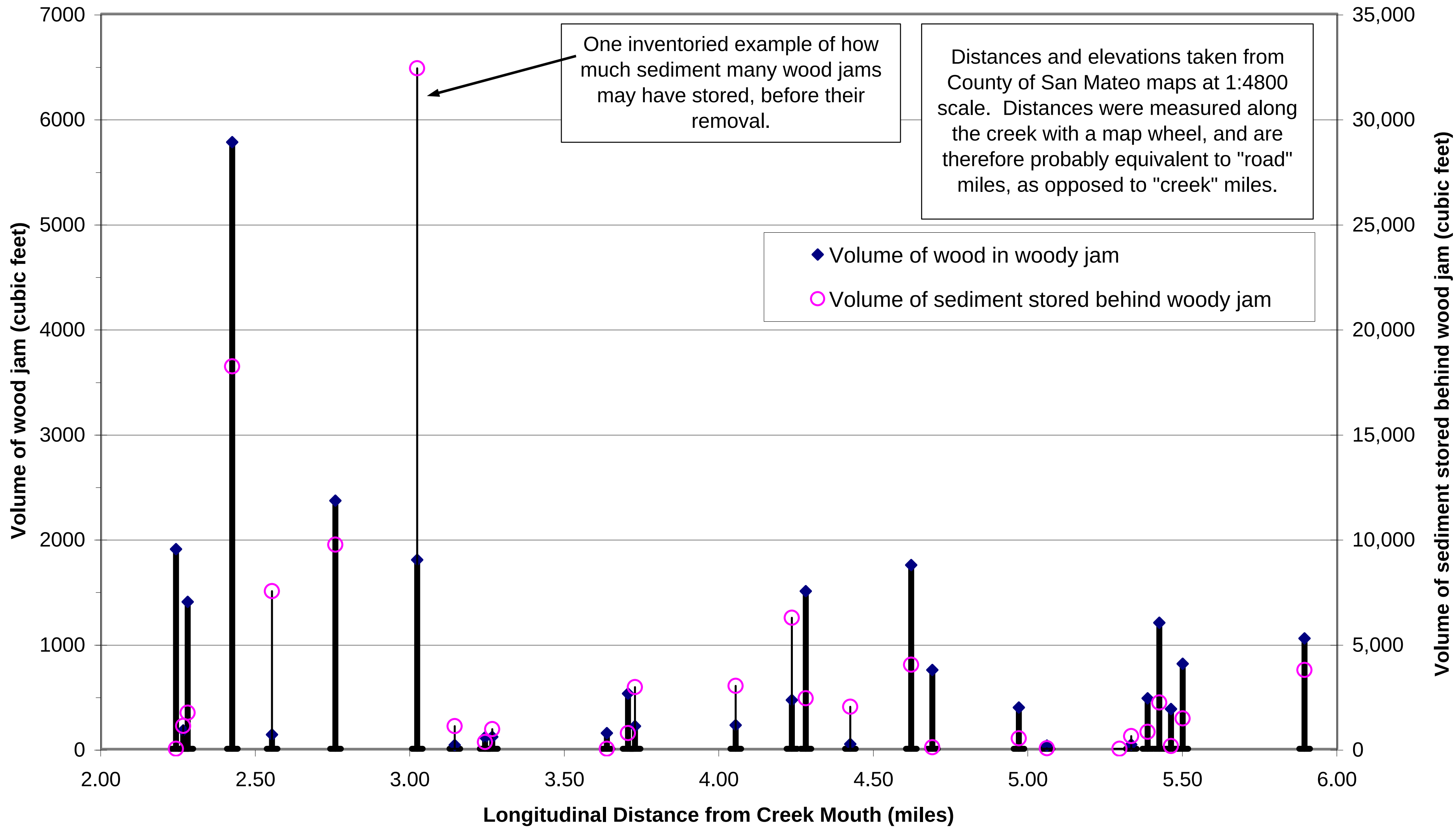

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Figure 6. Wood jam location, size, and amount of sediment stored: Gazos Creek upstream of Cloverdale Road. Generally, wood jams are not storing significant amounts of sediment in relation to the magnitude of sediment sources.

Table 4. Sediment transport measurements: Gazos Creek watershed, water years 2001 and 2002

	Site Conditions					Bedload Sampling Details						Sediment Transport			
Sample Date:Time	Observer(s)	Gage Height	Streamflow Discharge	Streamflow Value Source	Stream Condition	Active Bed Width	Sampler Width	No. of Verts.	Time/Vert.	Total Time	Sample Dry Weight	Bedload Discharge	Bedload Discharge	Suspended Sediment Concentration	Suspended Sediment Discharge
		(ft)	*(cfs)*	*M,R,E*	*R,F,B,U*	*(ft)*	*(ft)*		*(sec)*	*(sec)*	*(gm)*	*(lb/sec)*	*(tons/day)*	*(mg/l)*	*(tons/day)*
Gazos Creek above Highway 1 (about 1/2 mile upstream from Highway 1)															
3/4/01 12:30	jo, cw	-	30	E	R	bedload not measured						…	…	1500	121
11/29/01 7:45	bjm, sds	2.41	112	M	F	30	0.25	3	30	90	2277.9	6.70	281	830	250
11/29/01 10:35	bjm, sds	2.03	77.3	M	F	30	0.25	5	30	150	347.5	0.61	26	530	110
12/2/01 17:10	sds, cw	3.7	260	M	F	27	0.25	5	30	150	1214.9	1.93	81	1400	982
12/14/01 8:00	jo	2.04	42.3	M	F	15	0.25	7	20	140	717.5	0.68	28	300	34
12/21/01 11:50	jo, mtc	2.60	98	R	F	20.0	0.25	4	15	60	1500.0	4.41	185	580	153
12/28/01 17:00	sds, bjm	1.82	32.4	M	U	14.0	0.25	5	30	150	613.4	0.50	21.2	…	…
12/28/01 17:30	sds, bjm	1.82	32.4	M	U	14.0	0.25	5	30	150	597.5	0.49	20.6	61	5.3
1/2/02 15:55	sds, jo	4.90	525	E	P	bedload not measured, too deep and fast to wade						…	…	1,760	2492
1/11/02 15:12	jo	1.76	25.0	M	B	8.0	0.25	6	60	360	120.8	0.02	1.0	21	1.4
1/17/02 15:57	io. ch. smc	1.59	16.8	M	B	sand grains dancing, but too little to measure						…	0.01	…	…
2/13/02 10:45	io	1.44	10.1	M	B	sand grains dancing, but too little to measure						…	0.01	…	…
Gazos Creek at Cloverdale Road															
3/4/01 11:30	jo, cw	…	22.4	M	R	12	0.25	5	30	150	146.4	0.10	4.34	110	6.6
3/4/01 12:00	jo, cw	…	22.4	M	R	12	0.25	5	60	300	538.9	0.19	7.98	…	…
11/29/01 9:00	bjm, sds	…	117	M (surf.)	F	17	0.25	4	30	120	2062.3	2.58	108	250	79
12/2/01 16:05	sds, cw	…	300	M (surf.)	F									980	793
12/28/01 15:30	sds, bjm	…												15	0.0
1/2/02 16:30	jo, sds	…	350	E	F	bedload not measured, too deep and fast to wade						…	…	1000	944
1/11/02 16:20	jo	bent	15	E	B	5.0	0.25	2	60	120	73.6	0.03	1.1	14	0.6
Old Womans Creek															
12/28/02 13:25	sds, bjm	…	1.75	E	U									210	1.0
1/2/02 16:15	jo, sds	…	50	E	U	bedload not measured, too deep and fast to wade						…	…	2400	324
Slate Creek at Gazos Creek Road															
1/2/02 17:40	jo, sds	…	16	E	F	8.0	0.25	2	60	120	3320.9	1.95	82.0	660	28.5
Bear Gulch															
1/2/02 16:50	jo, sds	…	40	E	F	7.0	0.25	3	30	90	1330.7	0.91	38.3	260	28.1
Gazos Creek Middle Fork at Mountain Camp															
12/21/01 10:45	jo	0.75	10	E	F	3.0	0.25	2	120	240	11.5	0.0013	0.05	37	1.0
1/2/02 17:20	jo, sds	1.63	30	E	F	6.0	0.25	3	60	180	238.9	0.07	2.9	130	10.5

Table 4. Sediment transport measurements:
Gazos Creek watershed, water years 2001 and 2002

	Site Conditions					Bedload Sampling Details						Sediment Transport			
Sample Date:Time	Observer(s)	Gage Height	Streamflow Discharge	Streamflow Value Source	Stream Condition	Active Bed Width	Sampler Width	No. of Verts.	Time/Vert.	Total Time	Sample Dry Weight	Bedload Discharge	Bedload Discharge	Suspended Sediment Concentration	Suspended Sediment Discharge
		(ft)	*(cfs)*	*M,R,E*	*R,F,B,U*	*(ft)*	*(ft)*		*(sec)*	*(sec)*	*(gm)*	*(lb/sec)*	*(tons/day)*	*(mg/l)*	*(tons/day)*

Notes and explanations:

Observers: bh= Barry Hecht; jo= Jonathan Owens; cw= Chris White; sds= David Shaw; bjm= Bonnie Mallory; sc= Shawn Chartrand; ch = Charlotte Hedlund

Streamflow Value Source: M = measured; R = rating curve; E = estimated

Stream Condition: R = rising, F = falling, B = baseflow, U = uncertain

Values for bedload and suspended load discharge having more than two to three digits displayed are the result of calculations, increased precision is not implied.

Streamflow discharge is the measured or estimated instantaneous flow when sediment was sampled, and usually differs from the mean flow for the day

Active Bed Width: The width thought by the field observer to be transporting significant amounts of bedload

Sampler Width and Type: 0.25 = 3-inch Helley Smith; 0.50 = 6-inch Helley Smith

Bedload Discharge (lbs/sec) = [active bed width (ft) * sample dry weight (gm) * 0.002205 (lbs)]/ [sampler width (ft) * sampling time (sec)]

Bedload Discharge (tons/day) = [active bed width (ft) * sample dry weight (gm) * 86,400 (sec)]/ [sampler width (ft) * sampling time (sec) * 907,200 (gm)]

Sample Dry Weights in parentheses are temporary Wet Weights w/plastic bags

Observations of no bedload in motion are given a value of 0.01 tons per day so they can be plotted as threshold data.

Many early and late-season suspended-sediment samples reported below the detection limit of 5 mg/l; the detection limit has been converted to tons/day so that it can be plotted.

year 2002 was approximately 10,000 tons of sediment (Appendix H-S, Form 2). A more detailed account of this method is included in Appendix H-S.

4.1 Types of sediment transport

We distinguish two types of sediment in transport. Bedload sediment is supported by the bed; it rolls and saltates along the bed, commonly within the lowermost 3 inches. Movement can be either continuous or intermittent, but is generally much slower than the mean velocity of the stream. In Gazos Creek, bedload consists primarily of coarse sands and gravels. Suspended sediment is supported by the turbulence of the water, and is transported at a rate approaching the mean velocity of flow. In Gazos Creek, as elsewhere, suspended sediment consists of fine sands, silts, and clays. Dissolved minerals are also carried as ions in the water, but are not usually considered sediment.

For water year 2002, we calculated suspended-sediment discharge to be approximately 5,500 tons and bedload-sediment discharge to be approximately 4,800 tons (Table 2, and Appendix H-S, Form 2).

4.2 Sediment yield converted to landscape lowering rate

Several geologic studies have calculated uplift rates of the Santa Cruz Mountains over various long-term time periods. We wanted to compare sediment yields that we calculated to geologic uplift rates for the region. It should be noted that the large time-scale difference makes direct comparison difficult, but we hoped that this analysis would still be able to serve as guide to put water year 2002 in a longer-term perspective.

If a watershed is in equilibrium, then the lowering rate of the landscape should be similar to the uplift rate of the landscape. We can calculate a lowering rate by starting with our measured sediment yield, and then converting that mass of sediment into an equivalent thickness if it were uniformly distributed over the entire watershed; for this calculation we added in a factor to account for dissolved sediment. These results are presented in Table 2; for water year 2002 we calculated an equivalent lowering rate of 0.14 millimeters per year (mm/yr). This value falls at the low end of the range of published uplift rates, which range between 6 and 0.1 mm/yr (Valensise, G., 2002). Uplift rates are generally calculated on the scale of at least hundred thousand years; because of this long-term time scale so we would only expect them to correspond to long-term erosion and lowering rates, not year-to-year rates.

Compared to other creeks that we monitor, 0.14 mm/yr from Gazos Creek, for water year 2002, is similar to values from Corte Madera Creek (a creek noted for high sediment yields) and is higher than values from Los Trancos Creek (Table 2). Corte Madera and Los Trancos Creeks are in Portola Valley, on the inland side of the Santa Cruz Mountains, near Stanford University. Based on data from those creeks, we estimate that sediment yields in Gazos Creek for water year 1998 were at least 10 times higher than those that we calculated for water year 2002 (Table 3).

4.3 Sediment discharge during previous years

We wanted to compare sediment source totals from our inventory to our gaging-derived sediment-discharge data. As a very rough approximation we used the average lowering rates from Corte Madera and Los Trancos Creeks to estimate sediment discharge in Gazos Creek during previous years (Table 3). This correlation may or may not be valid, so we include a wide error band. The total we calculated is about 380,000 (+/- 150,000) metric tons, over the 5-year period which includes water years 1998 through 2002.

We would have expected this 5-year total based on sediment-discharge measurements to be about one-half of the value based on our sediment inventory, which represents sediment contributed from 1982 to the present. Given that the sediment inventory did not include all parcels within the watershed, small sediment sources, and only a few dirt-road inputs, we believe that the similarity of the sediment totals based on the two methods reinforces the validity of both methods.

4.4 Sediment discharge as a function of streamflow

During the end of water year 2001 and throughout water year 2002, Balance staff collected sediment samples from a number of locations throughout the watershed; the measurements are detailed in Table 4. As is described in Owens, Shaw and Hecht, 2003, we find it useful to plot sediment discharge as a function of streamflow. The measurements in Table 4 are plotted, as a function of streamflow, in Figures 7 and 8. Points that plot up and to the left are representative

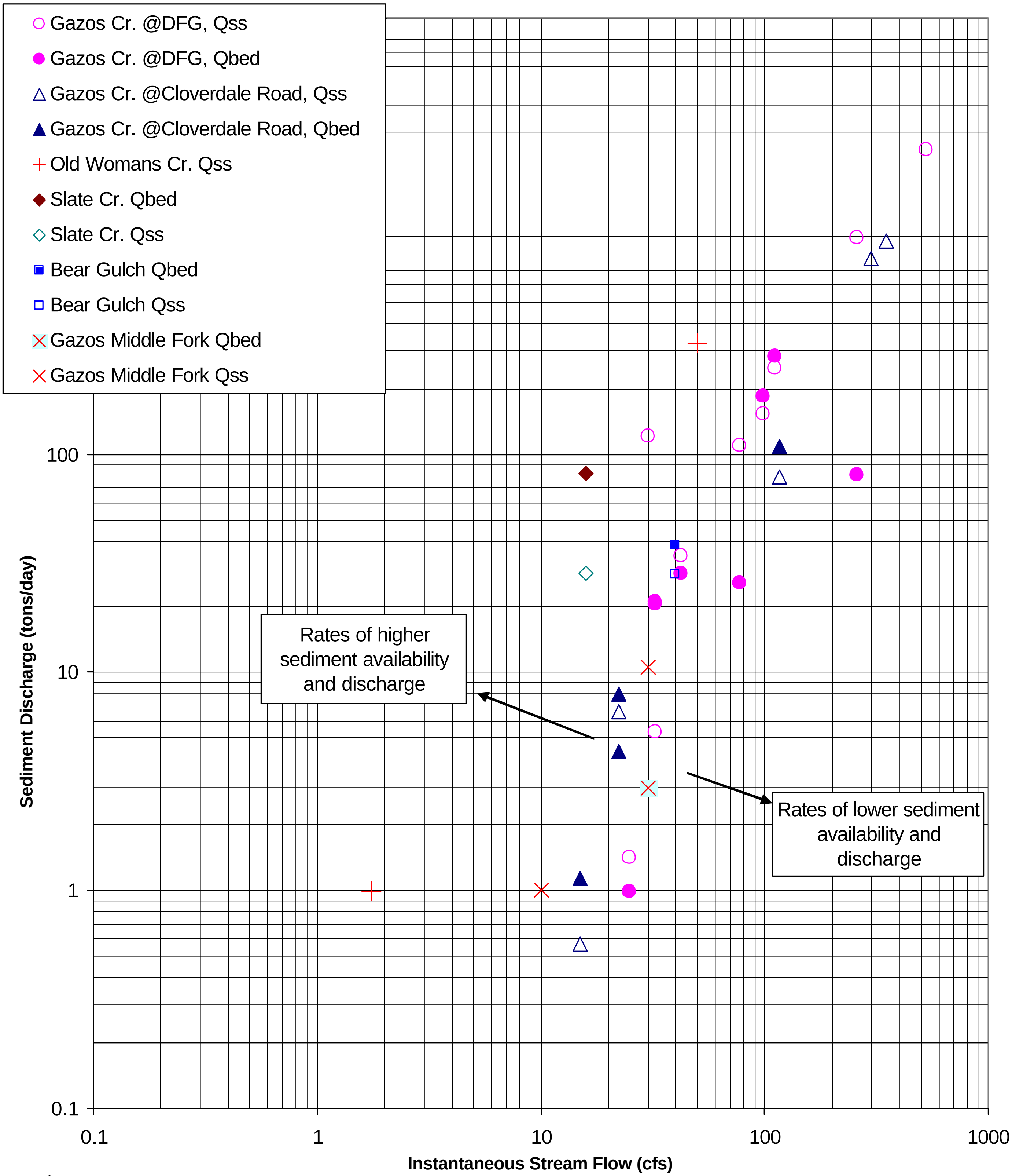

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Figure 7. Measured sediment transport rates (suspended load and bedload): Gazos Creek watershed, water years 2001 and 2002. Note that Old Woman Creek has high suspended-sediment concentrations, which influences downstream locations.

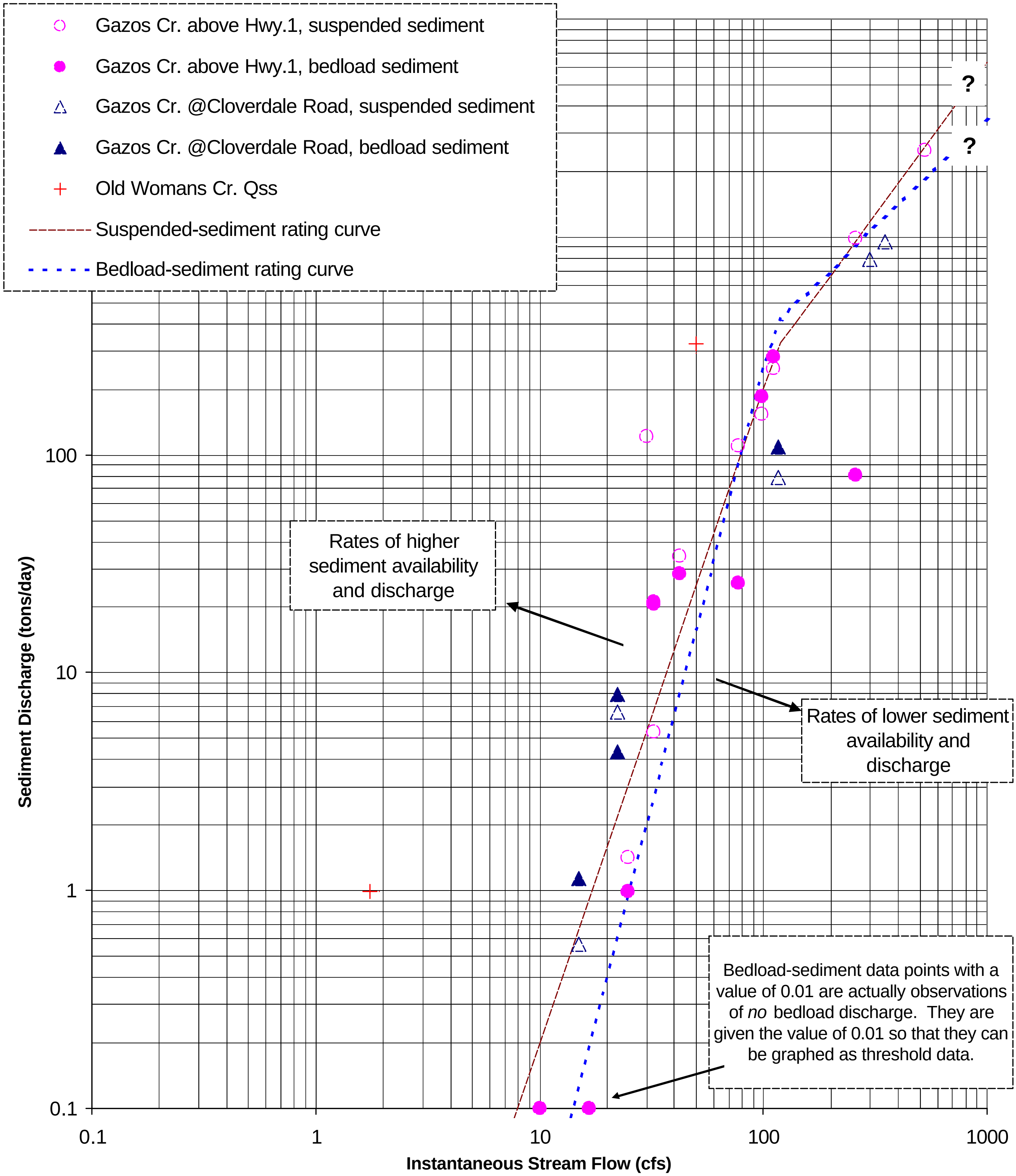

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Figure 8. Measured sediment discharge rates and estimated sediment rating curves: Gazos Creek, water years 2001 and 2002. Note that Old Woman Creek has high suspended-sediment concentrations which influences downstream locations.

of high sediment availability; points that plot down and to the right are representative of lower sediment availability. From this data, we conclude:

1. Sediment discharge rates during water year 2002 seem to be lower than rates during water year 2001. The decrease in rates since 2001 seems to indicate that Gazos Creek is still recovering from the large influx of sediment in 1998. We expect that sediment discharge rates for a given flow would have been even higher in water years 1998 through 2000.
2. Suspended-sediment values are greater in Gazos Creek at the GCDFG gage than are values in Gazos Creek at Cloverdale Road. The suspended sediment that causes this increase may come from gullies on the uplands north of the creek, or may come from Old Womans Creek.
3. Old Womans Creek contributes a large amount of suspended sediment compared to the rest of the watershed. Observations corroborate this finding, and add that high turbidity continues in Old Womans Creek well after a storm, when other creeks in the Gazos Creek watershed are running clear again. The impact of this persistent turbidity is to decrease the value of fish habitat in Gazos Creek downstream of Old Womans Creek.
4. Slate Creek also contributes a large amount of sediment given its watershed area. Sediment from Slate Creek is mainly bedload sediment; however, Slate Creek conclusions are only based on one set of measurements.

These conclusions are based on a limited number of data points, especially for the smaller tributaries. Additional data would help clarify and quantify the trends that we have tentatively identified.

4.5 Scour and Fill of Pool Habitat

In other regional creeks, we have observed that flows exceeding approximately 0.6 to 0.8 of the bankfull flow tend to scour pools, while smaller flows tend to fill pools. Depending on the size and timing of storms through a season, flow information can help predict whether pool habitat is improving (being scoured) or being filled. At our gaging location on Gazos Creek (about 0.4 miles upstream from Highway 1, Figure 1), we estimate morphological bankfull flow as approximately 840 cfs; the breakpoint between scouring and filling of the pools is therefore approximately 590 cfs at this location.

Gaging data that we collected allow us evaluate this analysis for Gazos Creek. During water year 2002, this model predicts that only the largest storm on December 2, 2001 (930 cfs) contributed to scouring pools, while the remainder of the storms that generated enough flow to transport bedload sediment would have contributed to pool filling.

5.0 CHANNEL STABILITY

In addition to our inventory of large channel-bank failures, we assessed channel stability with cross-section surveys and by comparing “morphological-bankfull” flow to “recurrence-interval-bankfull” flow. Our observations and measurements indicate that the channel is narrower and shallower downstream of mile 2.5, and the channel upstream of mile 2.5 is often deeper and wider, in relation to the bankfull level. This means that the channel is in better equilibrium in the downstream reaches than in the upstream reaches.

Sediment sources that we categorized as being channel-bank failures (Appendix A) were predominantly initiated in water year 1998. This makes sense with our observations that few terrace deposits formed as a result of high flows during 1998, compared to the large number of terraces formed in 1982. Many of the 1998 channel-bank failures were remobilizing sediment stored in terraces from 1956 or 1982.

5.1 Repeat cross-section survey

One way that we assessed channel stability was to resurvey ten creek cross sections that had been initially surveyed in the summer of 1998, after a log jam had been removed at this site (EPA Site Q, also known as Site 9S), the location is shown in Figure 1. This log jam was removed along with many others in May, 1998. Those cross sections that we resurveyed had become wider and deeper, both upstream and downstream of the removed log jam location (Figures 9 to 14). Figures 9 and 10 are upstream of the wood jam location; figures 11 to 14 are downstream of the former wood jam location. We resurveyed these cross sections in January of 2002, so we also surveyed the high-water marks from water year 2002.

The initial ten cross-section surveys were performed in September of 1998, largely by volunteers who were not fully conversant in surveying techniques. Upon comparison, with the 2002 survey data, we concluded that not all of the initial data were valid. We evaluated the validity of the data by comparison of the surveyed locations and elevations of the monumented survey endpoints, and by comparison to observations of changes in channel shape, such as a freshly scoured bank. Plots of the valid cross-sections are shown in Figures 9 through 14; the invalid cross sections are not shown.

5.2 Bankfull height

At Balance's gaging station (Appendix H-S), we have concluded that the peak flow (930 cfs) was slightly above the "top of bank", which corresponds to a "morphological-bankfull" flow of 840 cfs (Figure H-5, in the Gazos Creek Hydrologic Assessment). Peak flows for many other regional gaging stations were close to "bankfull" return periods of 1.5-year to 2-year recurrence intervals for water year 2002. At the locations that we resurveyed, the high-water marks from water year 2002 were generally below the morphological top of bank (Figures 9, 10, 12, and 13). We observed in Gazos Creek that most locations downstream of Cloverdale Road have a channel where the bankfull morphology matches the bankfull recurrence interval, while most locations upstream of Cloverdale road have an entrenched channel where the morphological bankfull is larger than the recurrence-interval bankfull.

An entrenched (downcut) channel focuses more of the creek's hydraulic energy on the bed and banks than a channel where high flows spill out onto a vegetated floodplain and much of the hydraulic energy is dissipated by the resistance of the vegetation.

This leads us to believe that the Gazos Creek channel upstream from Cloverdale Road is prone to further entrenchment, or to over widening where bedrock prevents entrenchment. Bedrock is already evident in many places along the bed, and we observed that many section of the creek channel seemed too wide, so overwidening may already be occurring. This overwidening will tend to destabilize banks along the creek, as seen in the channel-bank types of sediment sources we inventoried.

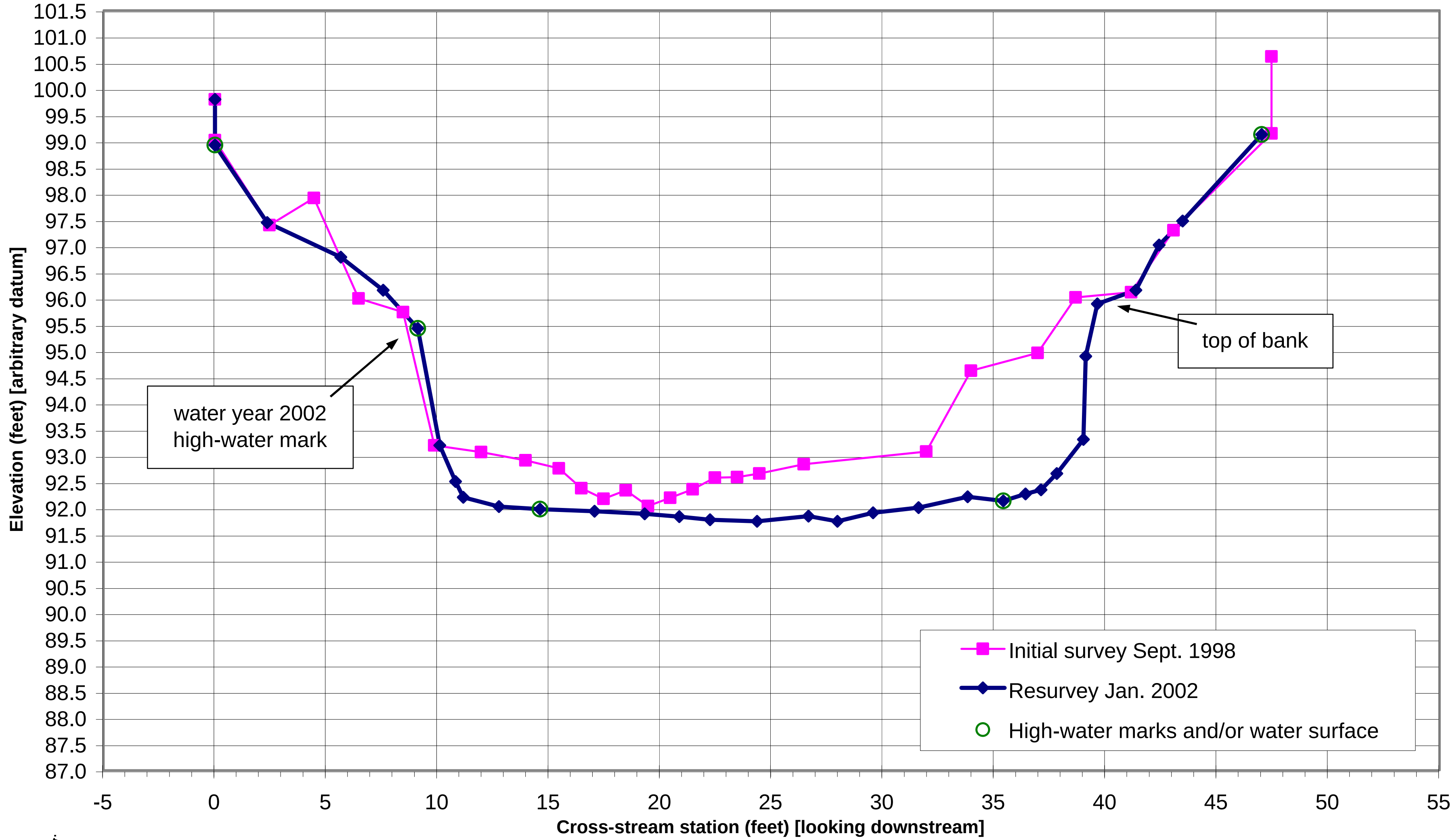

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Figure 9. Cross-section survey plot: site 9S-2, Gazos Creek. Note general trend of incision and/or widening since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.

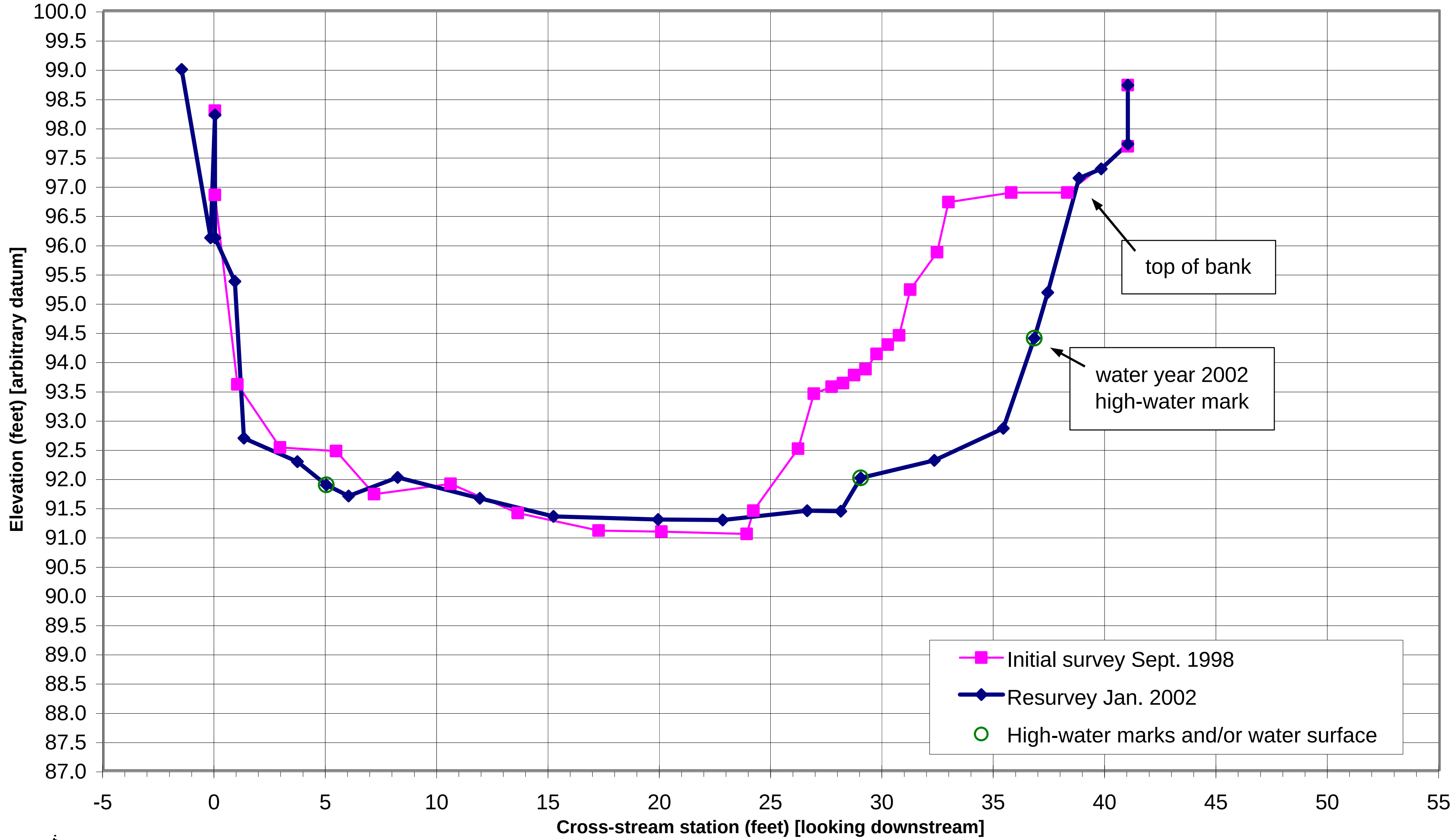

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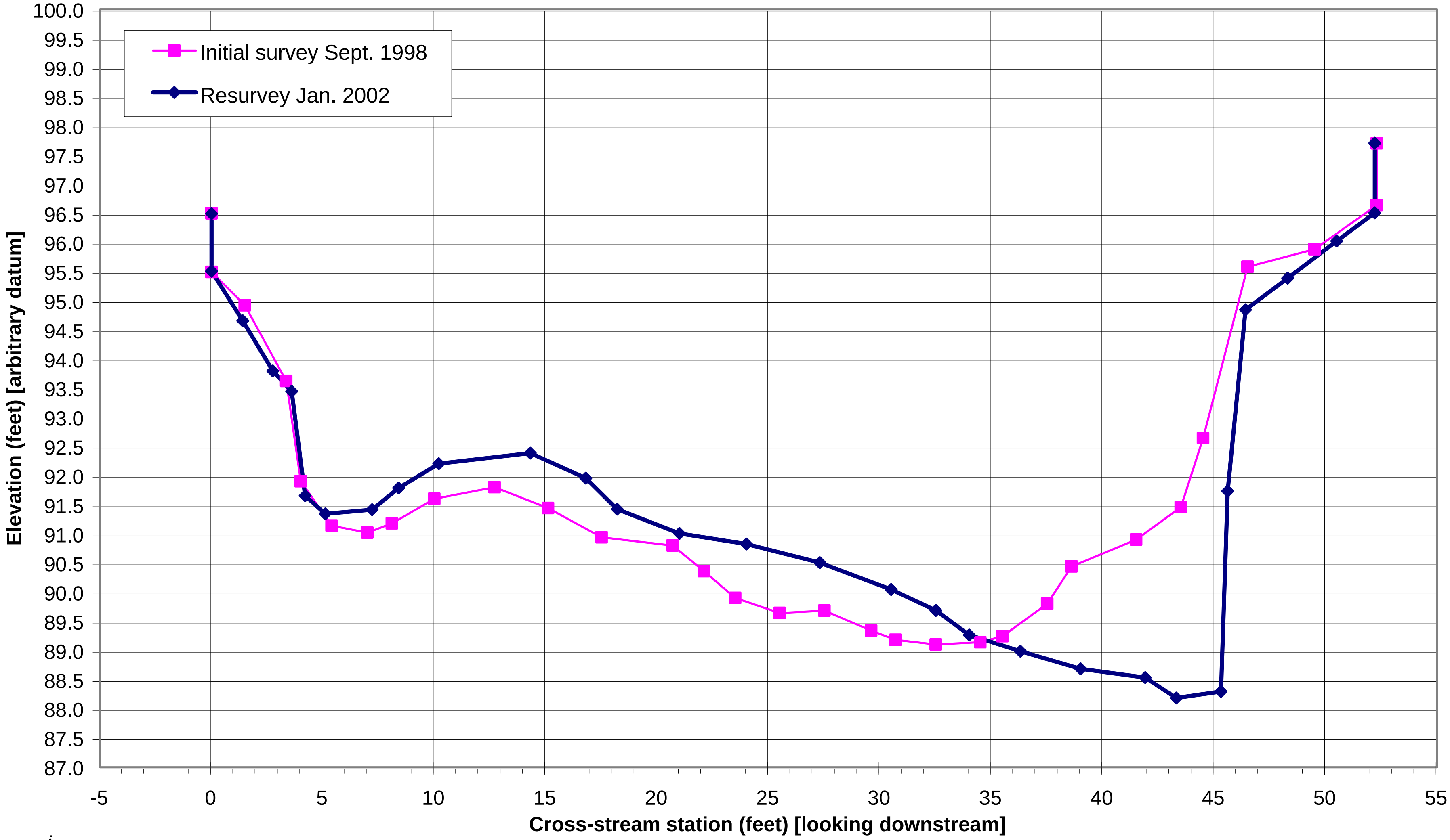
Figure 10. **Cross-section survey plot: site 9S-4, Gazos Creek.** Note general trend of incision and/or widening since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.



Balance Hydrologics, Inc.

Figure 11. **Cross-section survey plot: site 9S-7, Gazos Creek.** Note general trend of incision and/or widening since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.

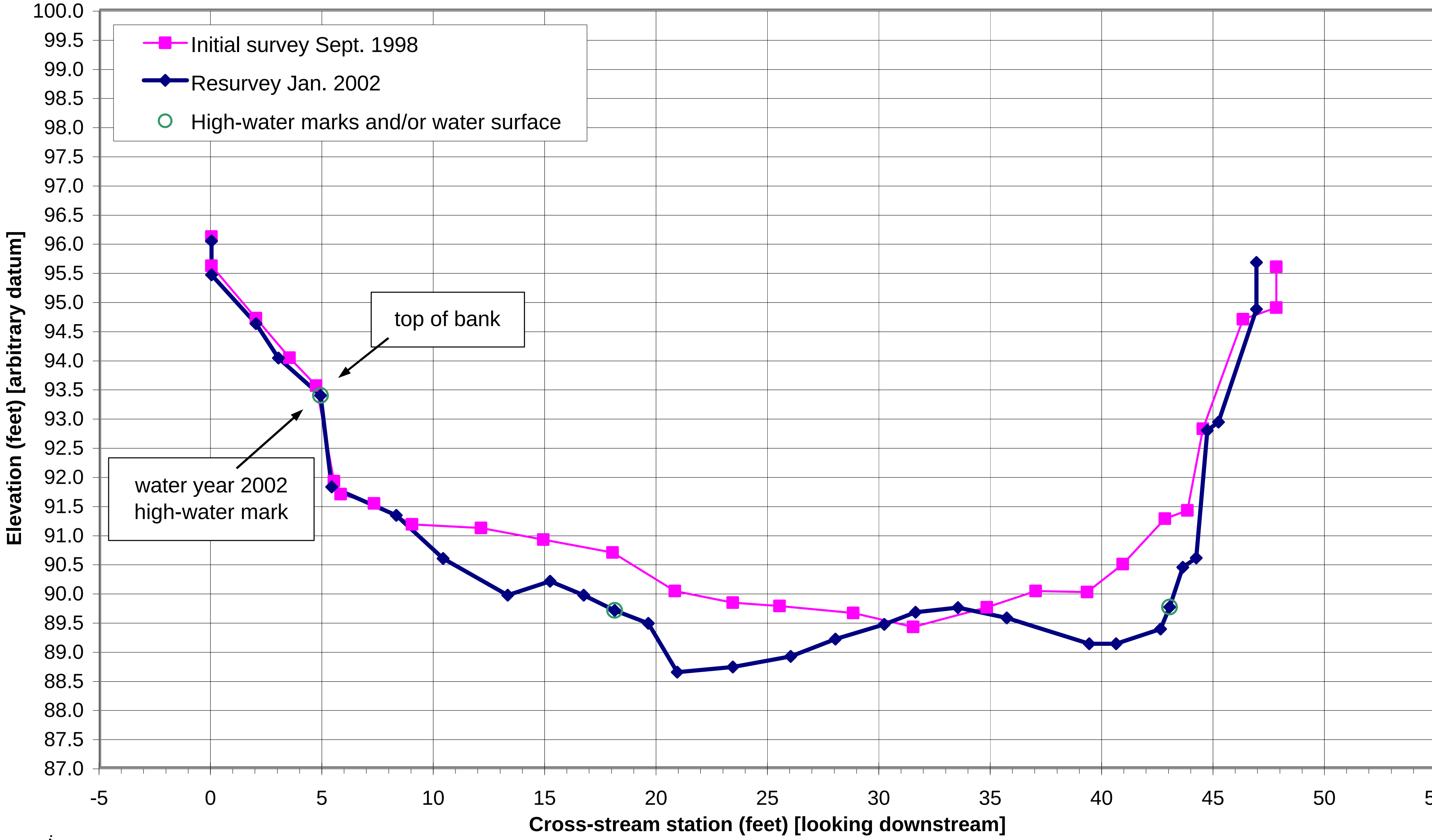


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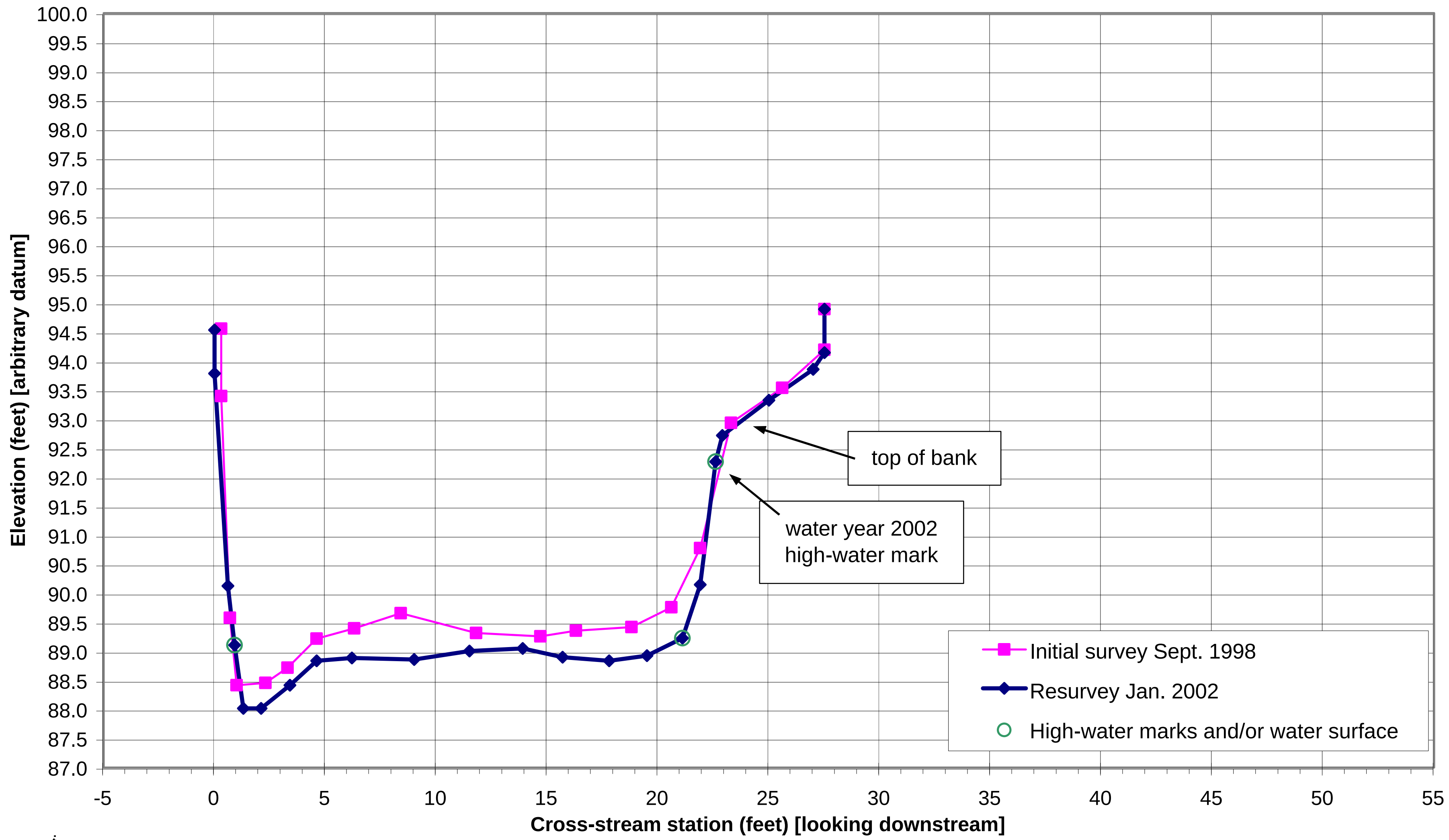
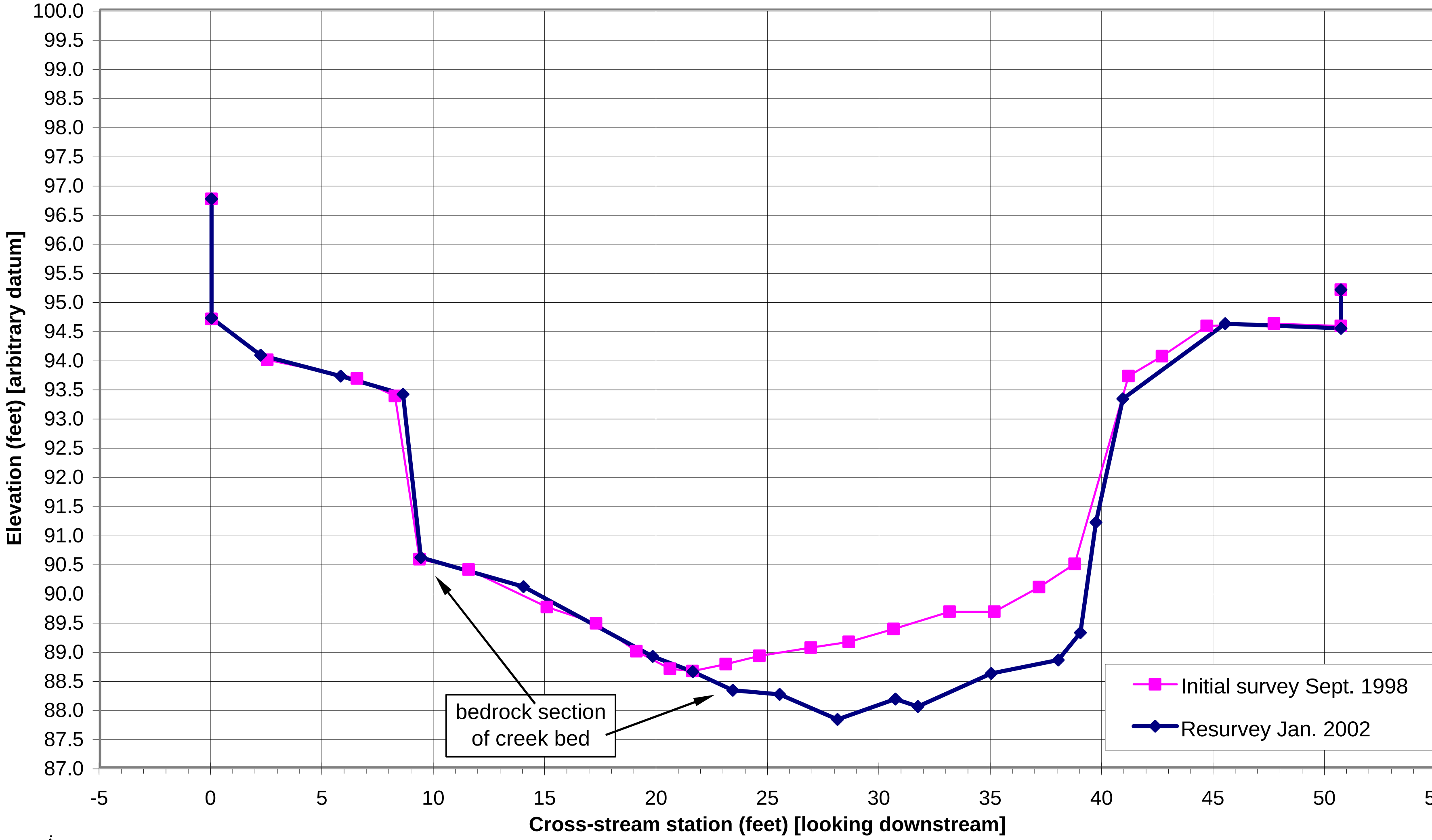
Figure 12. **Cross-section survey plot: site 9S-8, Gazos Creek.** Note general trend of incision and/or widening since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.



Balance Hydrologics, Inc.

Figure 13. **Cross-section survey plot: site 9S-9, Gazos Creek.** Note general trend of incision since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.



Balance Hydrologics, Inc.

Figure 14. **Cross-section survey plot: site 9S-10, Gazos Creek.** Note general trend of incision since 1998. Survey performed using auto level, tripod, rod, and fiberglass tape.

If the bed of the creek can be raised, then high flows would flow onto the flow plain sooner during a flood. If enough wood jams were present, sufficient sediment could be trapped to raise the bed level of the creek so that flow would interact with the floodplain more frequently. The wood jams would also slow the water down by the increased turbulence that they create.

6.0 REFERENCES

Hecht, B., and Golling, R., 1982, Selected physical and chemical characteristics of diatomaceous mudstones, Big Basin Redwoods State Park area: Cooperators' Research Report #2 to California Division of Beaches & Parks, Santa Cruz Mountains Unit, 15 p.

Hecht, B., and Rusmore, B., eds., 1973, Waddell Creek -- the environment around Big Basin: Sempervirens Fund and the University of California, Santa Cruz, 98 p. + appendix

Owens, J., Brown, S., and Hecht, B., 2002. Annual hydrologic record and sediment yield for Corte Madera Creek, Portola Valley, California: data report for water year 2002. In preparation: consulting report for Stanford University Facilities Department, November.

Owens, J., Chartrand, S., and Hecht, B., 2002. Annual hydrologic record and sediment yield for Corte Madera Creek, Portola Valley, California: data report for water year 2001. Consulting report for Stanford University Facilities Department, May.

Owens, J., Shaw, D., and Hecht, B., 2003. Annual hydrologic record and sediment yield for Gazos Creek above Highway 1, San Mateo County, California: data report for water year 2002. Draft consulting report prepared by Balance Hydrologics for Coastal Watershed Council, April, 9 p. (also referred to as Appendix H-S to the hydrology section)

Singer, S.W., 2000. An erosion control plan for the Gazos Creek Uplands of Cloverdale Ranch. Consulting report prepared by Steven Singer Environmental & Ecological Services, for Peninsula Open Space Trust, April.

Valensise, G., 2002. Geologic assessment of the relative contribution of strike-slip faulting, reverse-slip faulting and bulk squeezing in the creation of the central Santa Cruz Mountains, California. Instituto Nazionale de Geofisica, Italy.

APPENDIX A.

Sediment source volumes:
Gazos Creek and tributaries

Appendix A. Sediment source volumes: Gazos Creek and tributaries
Inventory performed October 2001
(positive volumes indicate a sediment source, negative volumes indicate sediment storage)

Site ID	Type	Height	Length	Depth/ thickness	Shape factor	Sediment Volume	% Bedload	Bedload Volume	Initiation year	Notes
	(cb, g, ls)	*(ft)*	*(ft)*	*(ft)*		*(ft^3)*	*(%)*	*(ft^3)*		
Bear Gulch sub-watershed										
BG-60	ls	100	60	3	1	18,000	50%	9,000	1998	Bear Gulch
BG-69	ls	300	120	5	1	180,000	50%	90,000	1998	
BG-70	ls	300	120	10	1	360,000	50%	180,000	1982	
BG-71	ls	100	50	1	1	5,000	50%	2,500	1998	
								0		
BG-100	ls	150	200	15	1	450,000	50%	225,000	1982	above+below road failure; tire walls
BG-320	ls	300	80	10	1	240,000	50%	120,000	1982	slide
BG-330	ls	200	70	20	1	280,000	50%	140,000	1982	road failure
BG-340	cb, ls	10	150	6	1	9,000	50%	4,500	1998	
BG-350	cb	30	40	8	1	9,600	50%	4,800	1998	
BG-400	df	20	80	3	-0.3	-1,440	100%	-1,440		60% remaining
BG-500	w	20	30	1.5	-0.5	-450	100%	-450		sed wedge
BG-501	cb	40	18	4	1	2,880	50%	1,440	1982	300' d/s from first BG confluence
BG-502	cb + ls	30	16	3	2	2,880	50%	1,440	1998	600' d/s from first BG confluence
BG-503	ls	150	35	6	3	94,500	50%	47,250	1982	not road induced, but sediment crossed road into BG
BG-504	cb	25	25	2	4	5,000	50%	2,500	1998	stream at bedrock; BH notes for fix idea
BG-505	ls	75	30	2	5	22,500	50%	11,250	1982	log at base directs flows into bank
BG-506	cb	14	10	7	6	5,880	50%	2,940	1998	below large ls
BG-507	ls	75	50	2	7	52,500	50%	26,250	1982	200' u/s of mainstem; not active does not contribute
BG-105	w	8	150	40	-0.5	-24,000	100%	-24,000		
BG-120							50%	0		
BG-125							50%	0		
BG-130	df	100	400	6	-0.8	-192,000	100%	-192,000		debris flow deposit at confluence, 80% remaining
Middle Fork Gazos Creek sub-watershed										
MSF-100	rd	6	150	16	1	14,400	75%	10,800	1950	Gazos Creek Road (road bed erosion)
MSF-101	rd	6	150	16	1	14,400	75%	10,800	1950	Gazos Creek Road (road bed erosion)
MSF-103	rd	10	150	20	1	30,000	75%	22,500	1950	Gazos Creek Road (road bed erosion)
MSF-104	rd	10	150	20	1	30,000	75%	22,500	1950	Gazos Creek Road (road bed erosion)
MSF-105	rd	9	300	20	1	54,000	75%	40,500	1950	Gazos Creek Road (road bed erosion)
MSF-110	ls, g	200	60	10	0.5	60,000	75%	45,000	1982	old road cut across base of slide
MSF-111	ls, g	150	50	10	1	75,000	75%	56,250	1920	aged by douglas fir regrowth; mudstone and sandstone
MSF-112	ls, g	300	50	5	1	75,000	75%	56,250	1982	several old roads cross toe area
North Fork Gazos Creek sub-watershed										
NMW-94	w	25	120	5	-0.25	-3,750	100%	-3,750		North/Main branch
NM-95	ls	30	30	1	1	900	50%	450	1956	old, revegetated; only small amount active
NM-96	ls	60	60	1	1	3,600	50%	1,800	1998	older larger LS not tabulated 200x200x5 80-90 years old
Slate Creek sub-watershed										
S-100	ls	125	100	3	1	37,500	50%	18,750	1982	200' u/s of main stem; assoc. w/ old road; 4 inches/year
Gazos Creek main stem										
M-97	ls	40	100	2	1	8,000	50%	4,000	1982	seep at base; below confluence w/ Middle Fork
M-98	ls	150	45	8	1	54,000	50%	27,000	1956	older than 1982, active in places
MW-99		30	30	4	-0.4	-1,440	100%	-1,440		
M-100	ls	140	150	15	1	315,000	100%	315,000	1982	creek cutting base of slide; big contributrions from 1998
MW-101	w	15	18	1	-0.5	-135	100%	-135		
MW-102	w	40	55	4	-0.25	-2,200	100%	-2,200		
M-103	ls	140	35	7	1	34,300	50%	17,150	1998	some vegeatative stabilization
MW-104	w	45	20	2	-0.45	-810	100%	-810		
M-105	cb	8	16	4	1	512	30%	154	1998	
MW-106	w	30	20	2	-0.5	-600	100%	-600		~100-year old redwood log
MW-107	w						50%	0		most already washed downstream
M-107	cb	7	53	26	1	9,646	50%	4,823	1998	wood jam diverted flow into bank
M-108	cb	7	25	8	1	1,400	20%	280	1998	bedrock creek bed

Appendix A. Sediment source volumes: Gazos Creek and tributaries
Inventory performed October 2001
(positive volumes indicate a sediment source, negative volumes indicate sediment storage)

Site ID	Type	Height	Length	Depth/ thickness	Shape factor	Sediment Volume	% Bedload	Bedload Volume	Initiation year	Notes
	(cb, g, ls)	*(ft)*	*(ft)*	*(ft)*		*(ft^3)*	*(%)*	*(ft^3)*		
M-109	cb	7	95	10	1	6,650	10%	665	1998	bed rock bed; old road crossing; d/s of pot-hole chute
M-110	cb	7	45	3.5	1	1,103	25%	276	1998	u/s of rip rap at EPA site T
M-111	cb	11	38	5.5	1	2,299	50%	1,150	1982	top of scarp at edge of road; 1982 and 1998
M-112	ls	30	80	5	1	12,000	50%	6,000	…	EPA site S; landslide mostly on road, rip rap below road
MW-113	w	6	9	1	-0.5	-27	100%	-27		
MW-114	w	67	15	1	-0.5	-503	100%	-503		
M-114	ls	45	70	11	1	34,650	50%	17,325	1995	redwoods slid down; stabilized by ferns + sapplings
M-115	cb	9	30	2	1	540	25%	135	1998	stumps failed, bank now undercut
M-115.5	ls	30	35	4	1	4,200	50%	2,100	1982	bedrock scarp, no loose sedimetn remaining
M-116	cb	13	23	7	1	2,093	20%	419	1998	old rewood in bed sheltering sediment in pool
M-117	cb	13	122	4	1	6,344	20%	1,269	1998	rip rap along base
MW-117	w	15	9	1	-0.5	-68	100%	-68		
MW-118	w	25	80	4	-0.5	-4,000	100%	-4,000		
M-118	ls, cb	35	35	9	1	11,025	30%	3,308	1998	log jam remains piled at bottom; EPA site Q
M-119	ls, cb	17	100	8	1	13,600	20%	2,720	1995	upper bank failure, lower bank accumulation
M-120	cb	14	35	5	1	2,450	50%	1,225	1998	cave-like feature
MW-121	w	100	20	2	-0.5	-2,000	100%	-2,000		
M-122	cb, ls	20	108	3	1	6,480	50%	3,240	1982	down to bedrock; removed log jam also at site
MW-123	w	80	20	3	-0.5	-2,400	100%	-2,400		
M-125	g, ls	600	50	20	0.5	300,000	50%	150,000	1998	gully debris flow; mostly 1998
M-125a	ls	300	50	10	0.5	75,000	50%	37,500	1998	side slump into top half of gully
MW-126	w	120	4	40	-0.325	-6,240	100%	-6,240	1998	
M-127	cb	25	35	5	1	4,375	50%	2,188		
M-128	g	600	50	20	0.5	300,000	50%	150,000	1982	vegetated seems stable
M-129	ls	40	50	5	1	10,000	50%	5,000	1982	old log jam at base; 1982 and 1998
M-130	ls + cb	30	150	8	1	36,000	50%	18,000	1998	three sections of scallops, just below road
M-131	cb	25	100	3	1	7,500	50%	3,750	1998	
M-132	ls	50	40	5	1	10,000	50%	5,000	1982	lots of vegetation stabilized, not reactivated
MW-133	w	50	30	4	-0.5	-3,000	100%	-3,000		old, sawmill site since 1905
M-134	cb	18	35	5	1	3,150	50%	1,575	1982	first failed in 1982, lower 2/3 fell in 1998
M-135	ls	20	30	3	1	1,800	50%	900	1982	25' in from creek; failures in 1982 and 1998
MW-136	w	35	80	3.5	-0.3	-2,940	100%	-2,940		
MW-137	w	50	30	2	-0.25	-750	100%	-750		
M-138	ls, cb	35	100	5	1	17,500	50%	8,750	1998	landslide triggered by bank failure
MW-139	w	1	1	1	-1	-1	100%	-1		minimal storage
M-140	cb	18	75	5	1	6,750	50%	3,375	1998	
M-141	cb	15	60	4	1	3,600	50%	1,800	1998	
M-142	g + ls	7	70	15	1	7,350	50%	3,675	1956	gully filled in 1956, then cleared in 1998 or '82
M-143	cb	20	65	8	1	10,400	50%	5,200	1998	scallop sections
MW-143	w	50	25	1.5	-0.5	-938	100%	-938		
MW-477	w	45	18	1	-0.4	-324	100%	-324		
MW-478	w	65	35	1	-0.475	-1,081	100%	-1,081		
MW-479	w	180	90	8	-0.25	-32,400	100%	-32,400		
M-480	ls	120	85	10	0.65	66,300	50%	33,150	1982	top still failing
M-481	cb	6	100	35	1	21,000	30%	6,300	1956	ongoing sediment contributions
M-482	cb	15	45	6	1	4,050	90%	3,645	…	base of large maples
M-483	cb	12	80	10	0.5	4,800	75%	3,600	…	redwoods across stream, wedge of sediment
M-484	ls	65	25	8	0.4	5,200	50%	2,600	1998	60% remaining;
M-485	ls	50	25	10	1	12,500	15%	1,875	1982	large gully at head of slide
MW-486	w	80	45	6	-0.45	-9,720	100%	-9,720		
M-487	cb	24	15	6	1	2,160	5%	108	1956	ongoing
M-488	cb	10	25	35	1	8,750	10%	875	1982	ongoing; seep at base of slide
M-489	cb	13	35	4	1	1,820	40%	728	1982	ongoing
M-490	cb	15	60	15	1	13,500	40%	5,400	1995	due to diverted flow from wood jam
M-491B	cb	9	65	20	1	11,700	80%	9,360	1998	due to diverted flow from wood jam
M-491A	cb	10	65	40	1	26,000	50%	13,000	1998	due to diverted flow from wood jam
MW-491	w	30	100	5	-0.5	-7,500	100%	-7,500		see notes; 5' aggradation; very large wood jam
MW-492	w	0	0	0	0	0	50%	0		
M-493	ls	30	80	5	1	12,000	50%	6,000	1982	still active
M-494	cb	12	40	15	1	7,200	50%	3,600	1998	caused by diverted flow from wood jam
MW-494	w	130	70	5	-0.4	-18,200	100%	-18,200		
M-495	cb	8	25	10	1	2,000	15%	300	2000	
M-496	cb	5	40	5.5	1	1,100	10%	110	2000	sand bank from 1998
MW-497	w	100	25	2.5	-0.275	-1,719	100%	-1,719		

Appendix A. Sediment source volumes: Gazos Creek and tributaries
Inventory performed October 2001
(positive volumes indicate a sediment source, negative volumes indicate sediment storage)

Site ID	Type	Height	Length	Depth/ thickness	Shape factor	Sediment Volume	% Bedload	Bedload Volume	Initiation year	Notes
	(cb, g, ls)	*(ft)*	*(ft)*	*(ft)*		*(ft^3)*	*(%)*	*(ft^3)*		
MW-498	w	101	26	1.5	-0.275	-1,083	100%	-1,083		
MW-499	w	0	0	0	0	0	50%	0		
Old Womans Creek sub-watershed										
Old-80	cb	75	60	5	1	22,500	50%	11,250	1982	
Old-100	mudflow	15	200	40	0.05	6,000	50%	3,000	1982	
Old-101	ls	25	65	8	1	13,000	50%	6,500	1989	
Oldw-101	w	10	20	75	-0.5	-7,500	100%	-7,500		
Oldw-102	w	10	20	40	-0.5	-4,000	100%	-4,000		
Old-103	g	200	40	6	1	48,000	50%	24,000	1982	
Oldw-103	w		minimal							
Oldw-182	w	5	10	60	-0.5	-1,500	100%	-1,500		causing 182a
Old-182a	ls	70	83	8	1	46,480	15%	6,972	1998	caused by landslide on opposite bank + log jam
Old-182b	cb	15	35	5	0.8	2,100	50%	1,050	1982	
Old-183	cb	8	30	5	1	1,200	50%	600	1998	
Old-184	ls	60	40	3	0.15	1,080	50%	540	1982	
Old-185	ls	100	100	8	0.4	32,000	50%	16,000	1982	
Old-186	cb slump	20	30	12	0.5	3,600	50%	1,800	1998	
Old-187	cb	20	30	5	1	3,000	50%	1,500	1998	
Oldw-188	w	minimal								
Old-188	cb	17	40	13	1	8,840	20%	1,768	1998	
Old-189	ls, g	80	40	8	0.9	23,040	50%	11,520	1982	
Oldw-190	w					0	50%	0		
Oldw-191	w	1	8	15	-0.4	-48	100%	-48		
Oldw-192	w	minimal								
Oldw-193	w	3	16	20	-0.3	-288	100%	-288		
Oldw-194	w	20	3	10	-0.3	-180	100%	-180		
Oldw-195	w	toe of 196				-4,813	100%	-4,813		
Old-196	ls, g	55	25	10	0.65	8,938	50%	4,469	1998	
Old-197	cb	20	100	5	1	10,000	50%	5,000	ongoing	
Old-198	cb	30	25	3	1	2,250	1%	23	1998	
Oldw-199	w	25	10	2	-0.15	-75	100%	-75		
Oldw-200	w	minimal								

Type of sediment source: cb= channel bank failure; g = gully; ls = landslide; w = wood jam; rd = road erosion.
Shape factor accounts for wedge shaped, or other shaped volumes, and is used to scale the otherwise simple multiplication of "height" x "length" x "depth".
Sediment sourves smaller than 1000 cubic feet were generally not inventoried.
Percent bedload was estimated at the source of the sediment by the percentage of large clasts in the remaining scarp (default value of 50% used unless otherwise noted);
stored bed material behind wood jams was estimated as 100% bedload.

APPENDIX B.

Wood jam data:
Gazos Creek and tributaries

Appendix B. Wood Jam Data: Gazos Creek and tributaries

Dates Collected: October and November, 2001

	wood jam dimensional data						calculations	other data		
Site I.D./ Reach	depth of d/s pool	height of wood jam	longitudinal length	x-sec. width	# of logs in jam	largest diameter log	volume of wood jam	u/s sediment storage	d/s bank scour	tree species in jam
	(feet)	*(feet)*	*(feet)*	*(feet)*	*(feet)*	*(feet)*	*(feet $^{3)}$*	*(cubic feet)*		
Old Womans Creek										
oldw-101	0.5	8	150	20	30		12000	7500	yes	redwoods
oldw-102	0.5	4	70	20	30		2800	4000	yes	redwoods
oldw-103		11	50	20	40		5500	0	yes	-
oldw-182		5	20	10	14		500	1500	yes	alder, cut redwoods
oldw-188		4	5	8	3		80	0	yes	alder
oldw-190		3	5	8	6		60	0	yes	alder
oldw-191		3	3	8	10		36	48	yes	alder
oldw-192	0.6	5.5	5	8	10		110	0	yes	alder
oldw-193	0.4	3.5	2	16	2		56	288	yes	alder
oldw-194	0.5	4	3	10	2		60	180	yes	alder
oldw-195	0.5	5	10	10	4		250	4813	yes	alder
oldw-199	0.4	3	3	10	5		45	75	yes	alder
oldw-200	0.5	5	4	10	5		100	0	yes	alder
North Fork Gazos Creek										
nm-94w	3	7	12	25	10	2.8	1050	3750	yes	redwood, alder
Gazos Creek main stem										
m-99w	1.3	4.5	12	30	15	2.5	810	1440	no	redwood, alder
mw-101	1.6	3.5	12	18	10	1.2	378	135	no	redwood, maple, lumber
mw-102	2	6	10	40	20		1200	2200	yes	alder, redwood
mw-104	2	6	8	20	10		480	810	no	?
mw-106	0.9	2	2	20	3		40	600	yes	redwood
mw-107								0		
mw-113	2	2	5	6	5		30	27	no	maple, stump
mw-114		3.5	15	15	4		394	503	yes	redwood, stump

Appendix B. Wood Jam Data: Gazos Creek and tributaries

Dates Collected: October and November, 2001

Site I.D./ Reach	wood jam dimensional data: depth of d/s pool	height of wood jam	longitudinal length	x-sec. width	# of logs in jam	largest diameter log	calculations: volume of wood jam	other data: u/s sediment storage	d/s bank scour	tree species in jam
	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet 3)	(cubic feet)		
mw-117	2	4.5	37	9	3	2.5	749	68	yes	redwood, alder
mw-118		7	20	25	20+		1750	4000	no	redwood
mw-121	1.8	3	1.5	20	7		45	2000	no	fir, softwood
mw-123	3.1	5	30	20	30+		1500	2400	no	cut redwoods
mw-126	2	4	5.8	40	7	5.8	464	6240	yes	
mw-133	3.5	4.5	2.5	40	2		225	3000	yes	redwood cribs
mw-136	1.9	3.5	3.5	35	9	3.5	214	2940	yes	redwood
mw-137	3.6	5	7	30	5		525	750	yes	redwood, evergreen
mw-139	1	2.5	4	30	7		150	1	no	?
mw-143	2.5	3	3	25	1		113	938	no	hemlock
mw-477	3.6	2	6	18	2		108	324	no	redwood
mw-478	3	1	2	35	2		35	1081	yes	redwood
mw-479		5	8	90	18		1800	32400	no	redwood
mw-486		7	15	45	100	5.5	2363	9720	no	
mw-492	2	1.5	4	45	3		135	7500	no	alder
mw-494	2	5	33	70	100+	3	5775	18200	no	redwood, alder, willow
mw-497	1.1	4	28	25	50		1400	1719	yes	redwood, alder
mw-498		4	3.5	25	-		175	1083	no	alder, redwood
mw-499	1.5	4	38	25	5	3	1900	0	no	alder
m-502w	1.6	4.5	25	25	20	3	1406	3125	yes	redwood, alder
m-503w	2.1	3	5	25	8		188	0	yes	maple, redwood, alder